During World War II, America's fledgling aeronautics industry hired black female mathematicians to fill a labor shortage. These "human computers" stayed on to work for NASA and made sure America won the Space Race. They fought for their country's future, and for their share of the American dream. This is their untold story.

HIDDEN FIGURES

MARGOT LEE SHETTERLY

CHAPTER TWO

Mobilization

There was no escaping the heat in the summer of 1943, not in the roiling seas of the South Pacific, not in the burning skies over Hamburg and Sicily, and not for the group of Negro women working in Camp Pickett's laundry boiler plant. The temperature and humidity inside the army facility were so intense that slipping outdoors into the 100-plus degrees of the central Virginia June summer invited relief.

The laundry room was both one of the war's obscure crannies and a microcosm of the war itself, a sophisticated, efficient machine capable of processing eighteen thousand bundles of laundry each week. One group of women loaded soiled laundry into the enormous boilers. Others heaved the sopping clothes into the dryers. Another team worked the pressing machines like cooks at a giant griddle. Thirty-two-year-old Dorothy Vaughan stood at the sorting station, reuniting wayward socks and trousers with the laundry bags of the black and white soldiers who came to Camp Pickett by the trainload for four weeks of basic training before heading on to the Port of Embarkation in Newport News. Small talk of husbands, children, lives back home, or the ever-present war rose above the thunder and hum of the giant laundry boilers and dryers. *We gave him a real nice send-off, whole neighborhood turned out. Just as well you can't get stockings nowhere, hot as it is. That Mr. Randolph sure is* *something, and friends with Mrs. Roosevelt too!* They brooded over the husbands and brothers and fathers heading into the conflict that was so far away from the daily urgencies of their lives in Virginia, yet so close to their prayers and their dreams.

The majority of the women who found their way to the military laundry room had left behind jobs as domestic servants or as stemmers in the tobacco factories. The laundry was a humid inferno, the work as monotonous as it was uncomfortable. Laundry workers existed at the bottom of the war's great pyramid, invisible and invaluable at the same time. One aircraft industry executive estimated that each laundry worker supported three workers at his plants; with someone else to tend to their dirty clothing, men and women on the production lines had lower rates of absenteeism. The laundry workers earned 40 cents an hour, ranking them among the lowest paid of all war workers, but with few job options available to them, it felt like a windfall.

Only a week had elapsed between the end of the school year at Robert Russa Moton, the Negro high school in Farmville, Virginia, where Dorothy worked as a math teacher, and her first day of work at Camp Pickett. As a college graduate and a teacher, she stood near the top of what most Negro women could hope to achieve. Teachers were considered the "upper level of training and intelligence in the race," a ground force of educators who would not just impart book learning but live in the Negro community and "direct its thoughts and head its social movements." Her in-laws were mainstays of the town's Negro elite. They owned a barbershop, a pool hall, and a service station. The family's activities were regular fodder for the social column in the Farmville section of the *Norfolk Journal and Guide*, the leading Negro newspaper in the southeastern United States. Dorothy, her husband, Howard, and their four young children lived in a large, rambling Victorian house on South Main Street with Howard's parents and grandparents.

In the summer of 1943, Dorothy jumped at the chance to head to Camp Pickett and earn extra money during the school break. Though teaching offered prestige, the compensation was modest. Nationally, Virginia's white teachers ranked in the bottom quarter in public school salaries, and their black counterparts might earn almost 50 percent less. Many black teachers in the South gave lessons in one- or two-room schools that barely qualified as buildings. Teachers were called upon to do whatever was necessary to keep the schoolhouses clean, safe, and comfortable for pupils. They shoveled coal in winters, fixed broken windows, scrubbed dirty floors, and prepared lunch. They reached into their own threadbare purses when the schoolroom kitty fell short.

Another woman in Dorothy's situation might have seen the laundry job as unthinkable, regardless of the economics. Wasn't the purpose of a college degree to get away from the need to work dirty and difficult jobs? And the location of the camp, thirty miles southeast of Farmville, meant that she lived in worker housing during the week and got back home only on weekends. But the 40 cents an hour Dorothy earned as a laundry sorter bested what she earned as a teacher, and with four children, a summer of extra income would be put to good and immediate use.

And Dorothy was of an unusually independent mind, impatient with the pretensions that sometimes accompanied the upwardly mobile members of the race. She did nothing to draw attention to herself at Camp Pickett, nor did she make any distinctions between herself and the other women. There was something in her bearing that transcended her soft voice and diminutive stature. Her eyes dominated her lovely, caramel-hued face—almond-shaped, wide-set, intense eyes that seemed to see everything. Education topped her list of ideals; it was the surest hedge against a world that would require more of her children than white children, and attempt to give them less in return. The Negro's ladder to the American dream was missing rungs, with even the most outwardly successful blacks worried that at any moment the forces of discrimination could lay waste to their economic security. Ideals without practical solutions were empty promises. Standing on her feet all day in the sweltering laundry was an opportunity if the tumbled military uniforms bought new school clothes, if each sock made a down payment on her children's college educations.

At night in the bunk of the workers' housing, as she willed a breeze to cut through the motionless night air, Dorothy thought of Ann, age eight, Maida, six, Leonard, three, and Kenneth, just eight months old. Their lives and futures informed every decision she made. Like virtually every Negro woman she knew, she struggled to find the balance between spending time with her children at home and spending time *for* them, for her family, at a job.

Dorothy was born in 1910 in Kansas City, Missouri. Her own mother died when Dorothy was just two years old, and less than a year later, her father, Leonard Johnson, a waiter, remarried. Her stepmother, Susie Peeler Johnson, worked as a charwoman at the grand Union Station train depot to help support the family. She took Dorothy as her own daughter and pushed her to succeed, teaching the precocious girl to read before she entered school, which vaulted her ahead two grades. She also encouraged her daughter's natural musical talent by enrolling her in piano lessons. When Dorothy was eight, the family relocated to Morgantown, West Virginia, where her father accepted a job working for a successful Negro restaurateur. There she attended the Beechhurst School, a consolidated Negro school located around the corner from West Virginia University, the state's flagship white college. Seven years later, Dorothy reaped the reward for her hard work in the form of the valedictorian's spot and a full-tuition scholarship to Wilberforce University, the country's oldest private Negro college, in Xenia, Ohio. The African Methodist Episcopal Sunday School Convention of West Virginia, which underwrote the scholarship, celebrated fifteen-year-old Dorothy in an eight-page pamphlet that it published and distributed to church members, lauding her intelligence, her work ethic, her naturally kind disposition, and her humility. "This is the dawn of a life, a promise held forth. We who have been fortunate enough to guide that genius and help mold it, even for a little while, will look on with interest during the coming years," wrote Dewey Fox, the organization's vice president. Dorothy was the kind of young person who filled the Negro race with hope that its future in America would be more propitious than its past.

At Wilberforce, Dorothy earned "splendid grades" and chose math as her major. When she was an upperclassman, one of Dorothy's professors at Wilberforce recommended her for graduate study in mathematics at Howard University, in what would be the inaugural class for a master's degree in the subject. Howard, based in Washington, DC, was the summit of Negro scholarship. Elbert Frank Cox and Dudley Weldon Woodard, the first two Negroes to earn doctorates in mathematics, with degrees from Cornell and the University of Pennsylvania, respectively, ran the department. The white schools' prejudice was the black schools' windfall: with almost no possibility of securing a faculty position at a white college, brilliant black scholars like Cox and Woodard and W. E. B. Du Bois, the sociologist and historian who was the first Negro to receive a doctorate from Harvard, taught almost exclusively at Negro schools, bringing students like Dorothy into close contact with some of the finest minds in the world.

Howard University represented a singular opportunity for Dorothy, in line with the AME scholarship committee's lofty expectations. Possessed of an inner confidence that attributed no shortcoming either to her race or to her gender, Dorothy welcomed the chance to prove herself in a competitive academic arena. But the economic reality that confronted Dorothy when she came out of college made graduate study seem like an irresponsible extravagance. With the onset of the Great Depression, Dorothy's parents, like a third of all Americans, found steady work hard to come by. An extra income would help keep the household above water and improve the odds that Dorothy's sister might be able to follow her path to college. Dorothy, though only nineteen years old, felt it was her responsibility to ensure that the family could make its way through the hard times, even though it meant closing the door on her own ambitions, at least for the moment. She opted to earn a degree in education and pursue teaching, the most stable career for a black woman with a college degree.

Through an extensive grapevine, black colleges received calls from schools around the country requesting teachers, then dispatched their alumni to fill open positions in everything from tar paper shacks in the rural cotton belt to Washington, DC's elite Dunbar High School. New educators hoped to teach in their major subject, of course, but would be expected to assume whatever duties were necessary. After graduation in 1929, Dorothy was sent forth like a secular missionary to join the Negro teaching force.

Her first job, teaching math and English at a Negro school in rural Tamms, Illinois, ended after her first school year. The Depression-fueled collapse in cotton prices hit the area hard, and the school system simply shut its doors, leaving no public education for the rural county's Negro students. She fared no better in her next posting in coastal North Carolina, where, in the middle of the school year, the school ran out of money and simply stopped paying her. Dorothy supported herself and contributed to the family by working as a waitress at a hotel in Richmond, Virginia, until 1931, when she got word of a job at the school in Farmville.

It was no surprise that the newcomer with the beautiful eyes caught the attention of one of Farmville's most eligible bachelors. Tall, charismatic, and quick with a smile, Howard Vaughan worked as an itinerant bellman at luxury hotels, going south to Florida in the winter and north to upstate New York and Vermont in the summer. Some years he found work closer to home at the Greenbrier, the luxury resort in White Sulphur Springs, West Virginia, which was a destination for wealthy and fabulous people from around the world.

Though her husband's work kept him on the road, Dorothy exchanged her traveling shoes for Farmville life and the routines of family, the stability of regular work, and community. Still, coming of age and entering the workforce in the depths of the Depression permanently affected Dorothy's worldview. She dressed plainly and modestly, spurned every extravagance, and never turned down the chance to put money in the bank. Though she was a member of Farmville's Beulah AME Church, it was the First Baptist Church that enjoyed her esteemed piano playing come Sunday morning, because they had hired her as their pianist.

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As the war intensified, the town post office was awash in civil service job bulletins, competing for the eyes of locals and college students alike. It was on a trip to the post office during the spring of 1943 that Dorothy spied the notice for the laundry job at Camp Pickett. But the word on another bulletin also caught her eye: mathematics. A federal agency in Hampton sought women to fill a number of mathematical jobs having to do with airplanes. The bulletin, the handiwork of Melvin Butler and the NACA personnel department, was most certainly meant for the eyes of the white, well-to-do students at the all-female State Teachers College there in Farmville. The laboratory had sent application forms, civil service examination notices, and booklets describing the NACA's work to the school's job placement offices, asking faculty and staff to spread the word about the open positions among potential candidates. "This organization is considering a plan to visit certain women's colleges in this area and interview senior students majoring in mathematics," the laboratory wrote. "It is expected that outstanding students will be offered positions in this laboratory." Interviews that year yielded four new Farmville girls for the laboratory's computing sections.

Dorothy's house on South Main sat down the street from the college campus. Every morning as she walked the two blocks to her job at Moton High School, a U-shaped building perched on a triangular block at the south end of town, she saw the State Teachers College coeds with their books, disappearing into classrooms in their leafy sanctuary of a campus. Dorothy walked to school on the other side of the street, toeing the invisible line that separated them.

It would no sooner have occurred to her that a place with so baroque a name as the Langley Memorial Aeronautical Laboratory would solicit an application from Negro women than that the white women at the college across the street would beckon her through the front doors of their manicured enclave. Black newspapers, however, worked indefatigably to spread the word far and wide about available war jobs and exhorted their readers to apply. Some were dubbing Executive Order 8802 and the Fair Employment Practices Committee "the most significant move on the part of the Government since the Emancipation

Proclamation." Dorothy's own sister-in-law had moved to Washington to take a job in the War Department.

In the first week of May 1943, the *Norfolk Journal and Guide* published an article that would call to Dorothy like a signpost for the road not taken. "Paving the Way for Women Engineers," read the headline. The accompanying photo showed eleven well-dressed Negro women in front of Hampton Institute's Bemis Laboratory, graduates of Engineering for Women, a war training class. Founded in 1868, Hampton Institute had grown out of the classes held by the free Negro teacher Mary Peake, in the shade of a majestic tree known as the Emancipation Oak. On the eve of World War II, Hampton was one of the leading Negro colleges in the country and the focal point of the black community's participation in the conflict.

The women had come from points up and down the East Coast, and from right there in town. Pearl Bassette, one of several Hampton natives, was the daughter of a well-known black lawyer, her family tracing its roots back to the early days of the city. Ophelia Taylor, originally from Georgia, graduated from Hampton Institute, and prior to starting the class was running a nursery school. Mary Cherry came from North Carolina, Minnie McGraw from South Carolina, Madelon Glenn from faraway Connecticut. Miriam Mann, a tiny firebrand who had taught school in Georgia, had come to the city with her family when her husband, William, accepted a position as an instructor teaching machine shop at the US Naval Training School at Hampton Institute.

There were black jobs, and there were *good* black jobs. Sorting in the laundry, making beds in white folks' houses, stemming in the tobacco plant—those were black jobs. Owning a barbershop or a funeral home, working in the post office, or riding the rails as a Pullman porter—those were *good* black jobs. Teacher, preacher, doctor, lawyer—now those were *very* good black jobs, bringing stability and the esteem that accompanied formal training.

But the job at the aeronautical laboratory was something new, something so unusual it hadn't yet entered the collective dreams. Not even

the long-stalled plan to equalize Negro teachers' salaries with those of their white counterparts could beat this opportunity. Even if the war ended in six months or a year, a much higher salary even for that brief time would bring Dorothy that much closer to assuring her children's future.

So that spring, Dorothy Vaughan carefully filled out and mailed two job applications: one to work at Camp Pickett, where the need for labor was so great, so undifferentiated, that there was virtually no possibility that they would not hire her. The other, much longer application reviewed her qualifications in detail. Work history. Personal references. Schools attended: high school and college. Courses taken, grades received. Languages spoken (French, which she had studied at Wilberforce). Foreign travels (None). *Would you be willing to accept a position abroad?* (No). *Would you be willing to accept a position in Washington, DC?* (Yes). *How soon could you be ready to start work?* She knew the answer before her fingers carved it into the blank: 48 hours, she wrote. I can be ready to go within forty-eight hours.

CHAPTER ELEVEN

The Area Rule

In the early 1950s, there was rarely a slow workday for Dorothy Vaughan. With research activity concentrated on the West Side of Langley's campus, Dorothy managed a steady stream of computing jobs, dispatching incoming assignments to the women in her office and sending her computers out to various engineering groups located in the vicinity with greater frequency. Most of the work that came into the West Area computing office originated from one of the tunnels on the West Side or from the Flight Research Division, which was located in Building 1244, the West Side's new hangar. Though the East Side was now smaller in size and activity than Langley's booming West Side, facilities like the Spin Tunnel (a building shaped like a squat smokestack where engineers analyzed models subjected to dangerous spins) and Tanks nos. 1 and 2 (three-thousand-foot-long channels for testing seaplanes) remained busy. The Full-Scale Tunnel, the linchpin of the lab's World War II drag cleanup work, continued to test everything from low-speed aircraft designed with delta wings to helicopters. During intense periods, if the work exceeded the available hands, computing supervisors working in the East Area might put in a phone call to Dot Vaughan for reinforcements.

On one such occasion, two years after Mary joined West Computing, Dorothy Vaughan sent Mary to the East Side, staffing her on a project alongside several white computers. The routines of the computing work had become familiar to Mary, but the geography of the East Side was not. Her morning at the East Side job proceeded without incident—until nature called.

"Can you direct me to the bathroom?" Mary asked the white women.

They responded to Mary with giggles. How would *they* know where to find *her* bathroom? The nearest bathroom was unmarked, which meant it was available to any of the white women and off-limits to the black women. There were certainly colored bathrooms on the East Side, but with most black professionals concentrated on the West Side, and fewer new buildings on the East Side, Mary might need a map to find them. Angry and humiliated, she stormed off on her own to find her way to *her* restroom.

Negotiating racial boundaries was a daily fact of Negro life. Mary wasn't naive about the segregation at Langley—it was no different than anywhere in town. Yet she couldn't shake this particular incident. It was the proximity to professional equality that gave the slight such a surprising and enduring sting. Unlike the public schools, where minuscule budgets and ramshackle facilities exposed the sham of "separate but equal," the Langley employee badge supposedly gave Mary access to the same workplace as her white counterparts. Compared to the white girls, she came to the lab with as much education, if not more. She dressed each day as if she were on her way to a meeting with the president. She trained the girls in her Girl Scout troop to believe that they could be anything, and she went to lengths to prevent negative stereotypes of their race from shaping their internal views of themselves and other Negroes. It was difficult enough to rise above the silent reminders of Colored signs on the bathroom doors and cafeteria tables. But to be confronted with the prejudice so blatantly, there in that temple to intellectual excellence and rational thought, by something so mundane, so ridiculous, so universal as having to go to the bathroom . . . In the moment when the white women laughed at her, Mary had been demoted from professional mathematician to a second-class human being, reminded that she was a black girl whose piss wasn't good enough for the white pot.

Still fuming as she walked back to West Computing later that day, Mary Jackson ran into Kazimierz Czarnecki, an assistant section head in the four-by-four-foot Supersonic Pressure Tunnel. A stocky fellow with a lantern jaw who played first base in the Langley softball league, Kazimierz Czarnecki—friends called him "Kaz"—was a native of New Bedford, Massachusetts, who had come to the laboratory in 1939 after graduating from the University of Alabama with an aeronautical engineering degree. His good nature and prodigious research output made him a well-liked, well-respected member of the laboratory staff. Before joining the four-foot SPT, Kaz had worked as a member of the Nine-inch Supersonic Tunnel research staff, which maintained an office in the Aircraft Loads Building, where West Area Computing was housed.

Most blacks automatically put on a mask around whites, a veil that hid the "dead-weight of social degradation" that scholar W. E. B. Du Bois gave voice to so eloquently in *The Souls of Black Folk*. The mask offered protection against the constant reminders of being American and the American dilemma. It obscured the anger that blacks knew could have life-changing—even life-ending—consequences if displayed openly. That day, however, as Mary Jackson ran into Kazimierz Czarnecki on the west side of the Langley Aeronautical Laboratory, there was no turning inward, no subversion, and no dissembling. Mary Jackson let her mask slip to the ground and answered Czarnecki's greeting with a Mach 2 blowdown of frustration and resentment, letting off steam as she ranted about the insult she had experienced on the East Side.

Mary Jackson was a soft-spoken individual, but she was also forthright and unambiguous. She chose to speak to everyone around her in the same serious and direct fashion, whether they were adolescents in her Girl Scout troop or engineers in the office. Mary was also a shrewd and intuitive judge of character, an emotionally intelligent woman who paid close attention to her surroundings and the people around her.

Whether her outpouring in front of Czarnecki was the spontaneous result of having reached a breaking point or something more astute, she picked the right person to vent to. What had started as one of the worst workdays Mary Jackson had ever had would end up being the turning point of her career.

"Why don't you come work for me?" Czarnecki asked Mary. She didn't hesitate to accept the offer.

While the national press published stories on Langley's link to the Rosenberg scandal, industry outlets like *Aviation Week* lauded the laboratory for two related advances that would revolutionize high-speed aircraft production: slotted walls in wind tunnels and an innovation known as the Area Rule.

The point of a wind tunnel, of course, was to simulate as closely as possible the conditions that prevailed in free flight. Interference from airflows bouncing off the solid walls of the test section, one of the phenomena examined by Margery Hannah and Sam Katzoff in their 1948 report, was one of the limitations of ground-based testing. The problem was most notable in the transonic range, as the eddies of air surrounding an object approached the speed of sound. A Langley researcher named Ray Wright had the intuition that cutting holes or slots in the walls of the wind tunnels would alleviate the interference effects, a concept that was proven when Langley built a small test tunnel with perforated walls. In 1950, they retrofitted the Sixteen-foot High-Speed Tunnel (rechristened the Sixteen-foot Transonic Dynamics Tunnel) with slotted walls and then did the same for the Eight-foot High-Speed Tunnel. Taming the tunnel interference was a "long sought technical prize" for the researchers, and in 1951 it earned John Stack and his colleagues another coveted Collier Trophy.

The new tunnel design set the stage for the second of the decade's significant developments. An engineer named Richard Whitcomb noticed that in the transonic speed range, the greatest turbulence occurred at the point where the wings of a model plane connected to its fuselage. Indenting the plane's body inward along that joint reduced the drag

dramatically and resulted in an increase of as much as 25 percent in the plane's speed for the same level of power. The Area Rule (so-called because the formula predicted the correct ratio of the area of a cross-section of a plane's wing to the area of the cross-section of its body) had the potential to have a greater impact on everyday aviation than supersonic aircraft, because of the thousands of aircraft whose operating speed topped out at the transonic range. The press had more than the usual fun with such an esoteric engineering concept, calling the new planes "wasp-waisted" and "Coke-bottle shaped" and talking about the "Marilyn Monroe effect." Whitcomb scored a sit-down with CBS news anchor Walter Cronkite and gained a measure of local celebrity ("Hampton Engineer Besieged by Public," read a somewhat hyperbolic *Daily Press* headline). In 1954, Whitcomb would take home Langley's third Collier Trophy in less than a decade.

For all the advances that had occurred on the laboratory's watch since 1917—cowled engines, laminar flow airfoils, supersonic research planes, an icing tunnel that led to improvements in flight safety in freezing temperatures—the existing body of aeronautical knowledge still sheltered unexplored corners. The investments in new and upgraded facilities on Langley's West Side made in the late 1940s and early 1950s were yielding research breakthroughs and impacting the nature of the assignments Dorothy handed out to her staff.

Unlike academically oriented research organizations, the NACA's laboratories always strove to live up to the "practical solutions" of their founding mission. The hands-on nature of the work at Langley was visible in the planes parked in the hangar, in the workshops where craftsmen built models to the engineers' specifications, in the work of the mechanics who affixed the models in the proper positions in the test sections, and in the guts of the powerful new tunnels like the Unitary Plan Tunnel, which looked like "an oil refinery under a roof." No matter how abstract the work or how conceptual the problem being solved, no one at Langley ever forgot that behind the numbers was a real-world goal: faster planes, more efficient planes, safer planes.

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Of course, the NACA wasn't such a bad place for the theoretical engineers either. Dorothy Hoover thrived in the Stability Analysis Division. By 1951, she had earned the lofty title of aeronautical research scientist, graded GS-9 in the government's revamped rating system. When Hoover's boss, R. T. Jones, left Langley for the NACA's Ames laboratory in 1946, Dorothy continued her work with the group's other notable researchers. Her Langley career reached a peak in 1951 with the publication of two reports, one with Frank Malvestuto, the other with Herbert Ribner, both of them detailed analyses of the swept-back wings that were now a standard feature of production aircraft. What the compressed-air and fresh-air engineers examined through direct observation, the theoreticians approached through fifty-page treatises in which one single equation might occupy the better part of a page. If research production was a measure of career viability—and it was—theoretical aerodynamics might have been the best place in the world to be a female researcher. Dorothy Hoover, Doris Cohen, and at least three other women published one or more reports with the group between 1947 and 1951. The leaders of the group clearly valued and cultivated the talent of their female members. Perhaps it was the remove from the brawnier aspects of engineering that made the theoretical group such a productive environment for women.

In 1952, Dorothy Hoover decided to take a leave of absence from the world of engineering and give herself over to the theoretical pursuits that were closest to her heart. She resigned from Langley and returned to her alma mater, Arkansas AM&N, for a master's degree in mathematics. Her thesis, "On Estimates of Error in Numerical Integration," was included in the 1954 proceedings of the Arkansas Academy of Science. That same year she enrolled in the University of Michigan under a John Hay Whitney Fellowship, a program designed to match talented Negro scholars with the country's most competitive graduate programs.

Mary Jackson, on the other hand, leaned in to the the engineer's paradise that was the NACA. With a background in math and physics, she brought to the job an understanding of the physical phenomena behind the calculations she worked on. And the Langley people were

busy people like her, running off after work to play on one of the laboratory's sports teams or attend a club meeting or lecture. Many of them tutored kids in math and science, something that Mary had done since graduating from college. Whether or not she had it planned at the time, Mary Jackson was on her way to becoming a Langley lifer.

During new-employee induction on her first day of work, Mary Jackson had met James Williams, a twenty-seven-year-old University of Michigan engineering grad and former Tuskegee airman who had fallen in love with airplanes as a teenager. Williams applied for engineering positions through the Civil Service but had been wary of moving to a state south of the Mason-Dixon Line. Langley's personnel officer, Melvin Butler, courted Williams energetically by phone, trying to convince him to accept the laboratory's offer. He even made arrangements for a place for Williams to live in Hampton. Further enticement was provided by a beautiful psychology grad student named Julia, who after graduation would be returning to her native Virginia. Butler, perhaps trying to circumvent complaints that might short-circuit his offer, did not disclose ahead of time to Langley's engineering staff that the newest recruit was black. Williams wasn't the first black engineer hired by Langley, but the couple of black men who preceded him had come and gone so quickly that not even their names remained in the institutional memory.

On his first day, Williams had had to convince the guards at the Langley security gate that he wasn't a groundskeeper or cafeteria worker so that he could get passed along for processing as an engineer. Several white supervisors refused him a place in their groups, but an influential branch chief in the Stability Research Division named John D. Bird—"Jaybird"—raised his hand right away to offer the young man a position. "Jaybird was as fair as it got," Williams's wife, Julia, remembered years later.

Not everyone in the group was as enthusiastic as Bird. "So how long do you think you're going to be able to hang on?" one new office mate teased, referring to the black engineers who had washed out. "Longer than you!" Williams retorted. Whereas the black women enjoyed the support that came from being part of a group, starting in a pool was not an option for a male engineer. Williams and the other black men who were soon to follow in his footsteps had a more solitary work life and faced aggressions that the women did not. But even though it was the black women who broke Langley's color barrier, paving the way for the black men now being hired, the women would still have to fight for something that the black men could take for granted: the title of engineer.

Soon after moving to the four-by-four-foot Supersonic Pressure Tunnel, Mary Jackson was given an assignment by John Becker, the chief of the Compressibility Division (compressibility referred to the compression of air molecules characteristic of faster-than-sound flight), Kazimierz Czarnecki's boss's boss's boss. Langley liked to think of itself as a place that eschewed bureaucracy, where an idea from a cafeteria worker could get a fair hearing if it were compelling enough. Division chiefs, just two rungs down from the top post in the laboratory, however, were Very Important People. John Becker, heir to John Stack and Eastman Jacobs and other NACA legends, ruled an empire composed of the Four-foot SPT and all the other tunnels devoted to supersonic and hypersonic research. Becker was the kind of guy the eager front-row boys from the top engineering programs would do anything to impress.

John Becker gave Mary Jackson the instructions for working through the calculations. She delivered the finished assignment to him just as she completed her work for Dorothy Vaughan, double-checking all numbers, confident that they were correct. Becker reviewed the output, but something about the numbers didn't seem right to him. So he challenged Mary's numbers, insisting that her calculations were wrong. Mary Jackson stood by her numbers. She and her division chief went back and forth over the data, trying to isolate the discrepancy. Finally, it became clear: the problem wasn't with her output but with his input. Her calculations were correct, based on the wrong numbers Becker had given her.

John Becker apologized to Mary Jackson. The episode earned Mary a reputation as a smart mathematician who might be able to contribute more than just calculations to her new group. Her showdown with John Becker was the kind of gambit that the laboratory expected, encouraged, and valued in its promising male engineers. Mary Jackson—a former West Computer!—had faced down the brilliant John Becker and won. It was a cause for quiet celebration and behind-the-scenes thumbs-up among all the female computers.

Most engineers were also good mathematicians. But it was the women who massaged the numbers, swam in the numbers, scrutinized the numbers until their eyes blurred, from the time they set their purses down on the desks in the morning until the time they put on their coats to leave at the end of the day. They checked each other's work and put red dots on the data sheets when they found errors—and there were very, very few red dots. Some of the women were capable of lightning-fast mental math, rivaling their mechanical calculating machines for speed and accuracy. Others, like Dorothy Hoover and Doris Cohen, had highly refined understandings of theoretical math, differentiating their way through nested equations ten pages deep with nary an error in sign. The best of the women made names for themselves for accuracy, speed, and insight. But having the independence of mind and the strength of personality to defend your work in front of the most incisive aeronautical minds in the world—that's what got you noticed. Being willing to stand up to the pressure of an opinionated, impatient engineer who put his feet up on the desk and waited while you did the work, who wanted his numbers done right and done yesterday, to spot the bug in his logic and tell him in no uncertain terms that he was the one who was wrong—that was a rarer quality. That's what marked you as someone who should move ahead.

mounted a day-in, day-out charm offensive: impeccably dressed, well-spoken, patriotic, and upright, they were racial synecdoches, keenly aware that the interactions that individual blacks had with whites could have implications for the entire black community. But the insecurities, those most insidious and stubborn of all the demons, were hers alone. They operated in the shadows of fear and suspicion, and they served at her command. They would entice her to see the engineer as an arrogant chauvinist and racist if she let them. They could taunt her into a self-doubting downward spiral, causing her to withdraw from the opportunity that Dr. Claytor had so meticulously prepared her for.

But Katherine Goble had been raised not just to command equal treatment for herself but also to extend it to others. She had a choice: either she could decide it was her presence that provoked the engineer to leave, or she could assume that the fellow had simply finished his work and moved on. Katherine was her father's daughter, after all. She exiled the demons to a place where they could do no harm, then she opened her brown bag and enjoyed lunch at her new desk, her mind focusing on the good fortune that had befallen her.

Within two weeks, the original intent of the engineer who walked away from her, whatever it might have been, was moot. The man discovered that his new office mate was a fellow transplant from West Virginia, and the two became fast friends. West Virginia never left Katherine's heart, but Virginia was her destiny.

CHAPTER THIRTEEN

Turbulence

At six months and counting, Katherine Goble's temporary assignment in the Flight Research Division was starting to look terribly permanent. So at the beginning of 1954, Dorothy Vaughan made her way to Building 1244 for a sit-down with Henry Pearson, the head of the branch that had "borrowed" her computer and forgotten to return her.

Katherine's offer to begin work at Langley in 1953 had come with a six-month probational appointment. Successful completion of the trial period would make her eligible for promotion from the entry level of SP-3 to SP-5, with the raise that accompanied it. Though Katherine had spent only two weeks physically in the West Area Computing office, she was still Dorothy's responsibility. Katherine could have been classified as a permanent member of West Computing, like the rest of the women who reported to Dorothy, available to rotate through other groups on temporary assignments. Or Henry Pearson could make Katherine an offer to officially join his group, as Kazimierz Czarnecki had done with Mary Jackson. One way or the other, however, Dorothy Vaughan and Henry Pearson needed to resolve Katherine Goble's situation.

"Either give her a raise or send her back to me," Dorothy said to Henry Pearson, sitting upstairs in his office in 1244. A Langley engineer in the old style, Pearson had graduated from Worcester Polytechnic in

Massachusetts and started work at the lab in 1930. He was a keen golfer, a horn-rimmed glasses wearer, the epitome of the New England WASP. Pearson was not a big fan of women in the workplace. His wife did not work; rumor had it that Mrs. Henry Pearson had been forbidden by her husband from holding a job.

As a branch chief attached to the high-profile Flight Research Division, Henry Pearson stood a level above Dorothy in the Langley management hierarchy. By the time Dorothy came to the laboratory in 1943, Pearson had already served as an assistant division chief for many years. Fearless as she was, Dorothy would have approached Henry Pearson even if she weren't a manager, but the official title of section head lent her additional authority. It put her on equal footing with the other female supervisors and—theoretically, at least—with men of the same rating, and it afforded her a degree of center-wide visibility. When calculating machine manufacturer Monroe asked Langley for its help producing a handbook on how to work algebraic equations with its machines, Dorothy was drafted as a consultant, working on a team with other well-respected women at Langley, including Vera Huckel from the Vibration and Flutter branch and Helen Willey of the Gas Dynamics complex.

The meeting between Dorothy Vaughan and Henry Pearson ended as they both knew it would, with Pearson offering Katherine Goble a permanent position in his group, the Maneuver Loads Branch, with a corresponding increase in salary. Dorothy's insistence also had a collateral effect: one of the white computers in the branch, in the same limbo position as Katherine, had herself gone to Pearson to petition for a raise. The white woman's request had fallen on deaf ears. *The rules are the rules*, Dorothy reminded Henry Pearson. Dorothy wielded her influence to win promotions for both Katherine and her white colleague.

The fact was, the engineers who worked for Henry Pearson realized soon after Katherine Goble took a seat at her desk in 1244 that their new computer was a keeper, and they had no intention of sending her back. Katherine's familiarity with higher-level math made her a versatile addition to the branch. Her library of graduate-school textbooks

crowded onto her desk next to the calculating machine, ready references if she needed them.

The Flight Research Division was a den of high-energy, free-thinking, aggressive, and very smart engineers. They and their brethren in the Pilotless Aircraft Research Division (PARD), a group specializing in the aerodynamics of rockets and missiles, spent their time not in the confines of the wind tunnels but in the company of live, fire-breathing, ear-splitting, temperamental metal projectiles. The "black-haired, leather-faced, crew-haircutted human cyclone" head of the Flight Research Division, Langley's chief test pilot, Melvin Gough, early in his engineering career had decided to take his life in his hands to train as a test pilot in order to improve the quality of his research reports. Testosterone filtered up from the hangar along with the jet-fuel fumes. It wasn't the kind of place that would exhibit particular patience for anyone, male or female, who took too long to scale the learning curve. Timidity in the Flight Research Division would get a girl nowhere.

Fortunately, Katherine Goble's confidence in her own mathematical abilities, and her innate curiosity, pushed her to pepper the engineers with questions, just as she had as a child with her parents and teachers. They fielded her inquiries with gusto: they could, and did, spend most of their lives talking and thinking about flight and would never run out of patience for the topic.

The Maneuver Loads Branch conducted research on the forces on an airplane as it moved out of stable, steady flight or tried to return to stable, steady flight. A sister branch, Stability and Control, developed the systems that would provide a plane with a smooth ride through rough air. The vehicles at the extreme experimental end of the aeronautical spectrum were the ones that made the romantic aeronautical engineer's heart beat faster—supersonic planes, hypersonic planes, planes capable of brushing the limits of space—but the transportation revolution fostered in no small part by Langley engineers like Henry Pearson had created a demand for research on vehicles designed for much more pedestrian pursuits. One of the tasks of the Maneuver Loads Branch was to examine safety concerns provoked by increasingly crowded skies.

One of the first assignments to land on Katherine's desk involved getting to the bottom of an accident involving a small Piper propeller plane. The plane, which was flying along in otherwise unremarkable fashion, literally fell out of the clear blue sky and crashed to the ground. The NACA received the plane's flight recorder, and the engineers assigned Katherine to analyze the photographic film record of the flight's vital signs, the first step in the search for answers as to what might have befallen the plane. For hours upon hours, day after day, she sat in a dark room and peered through a film reader, noting and writing down the airspeed, acceleration, altitude, and other metrics of the flight that were measured in regular time intervals over the course of the flight. The engineers specified any conversions to be applied to the raw data—converting, for example, miles per hour to feet per second—and supplied Katherine with the equations to be used to analyze the converted data. As a final step, Katherine plotted the data in order to give engineers a visual snapshot of the plane's disrupted flight.

Then the engineers set up an experiment re-creating the circumstances of the accident, flying a test plane into the trailing wake of a larger plane. The data from that, too, washed onto Katherine Goble's desk: seemingly endless hours, days, weeks, months of the same thing. It was typical eye-straining, monotonous computing work—and Katherine loved every moment of it.

When the engineers analyzed Katherine's reduced data, they were fascinated, realizing they were uncovering something they had not quite seen before. It turned out that the Piper had flown perpendicularly across the flight path of a jet plane that had just passed through the area. A disturbance caused by a plane could trouble the air for as long as half an hour after it flew through. The wake vortex of the larger plane had acted like an invisible trip wire: upon crossing the rough river of air left behind by the jet, the propeller plane stumbled in midair and tumbled out of the sky. That research, and other investigations like it, led to changes in air traffic regulations, mandating minimum distances between flight paths so as to prevent that kind of wake turbulence accident.

When Katherine Goble read the report, she found it "one of the most

interesting things she had ever read," and felt tremendous satisfaction to have participated in something that would have positive, real-world results. Her enthusiasm for the work, even the parts that others considered drudgery, was irrepressible. She couldn't believe her good fortune, getting paid to do math, the thing that came most naturally to her in the world.

She took a genuine liking to her new colleagues as well. The West Virginia engineer she had met on day one played oboe in a local symphony. Members of the Brain Busters Club convened after work and on weekends to build elaborate model airplanes by hand. Many of the men and women at Langley joined softball or basketball teams and played in local amateur leagues. Langley's "Skychicks" competed against a team fielded by the power company, the Kilowatt Cuties; over time, the black employees joined teams as well. And then there was the lunchtime bridge game. The game's requirement of both analytical and people-reading skills made it a favorite of the engineers, and they spent many a lunch hour in fierce competition. They were an opinionated, high-energy bunch, and best of all, as far as Katherine was concerned, they were all as smart as whips. There was nothing Katherine Goble loved more than *brains*.

From the very beginning, Katherine felt completely at home at Langley. Nothing about the culture of the laboratory or her new office rattled her—not even the persistent racial segregation. At the beginning, in fact, she didn't even realize the bathrooms were segregated. Not every building had a Colored bathroom, a fact that Mary Jackson had discovered so painfully during her rotation on the East Side. Though bathrooms for the black employees were clearly marked, most of the bathrooms—the ones implicitly designated for white employees—were unmarked. As far as Katherine was concerned, there was no reason why she shouldn't use those as well. It would be a couple of years before she was confronted with the whole rigmarole of separate bathrooms. By then, she simply refused to change her habits—refused to so much as enter the Colored bathrooms. And that was that. No one ever said another word to her about it.

She also made the decision to bring a bag lunch and eat at her desk, something many of the employees did. Why should she spend the extra money on lunch? It was more convenient as well; the cafeteria was just far enough from her building to have to drive, and who wanted to do that? And it was healthier too, what with the temptation of the ice cream that the cafeteria sold for dessert. Of course, for Katherine Goble, eating at her desk also had the benefit of removing the segregated cafeteria from her daily routine, another reminder of the caste system that would have circumscribed her movements and thoughts. Those unevolved, backward rules were the flies in the Langley buttermilk. So she simply determined to pluck them out, willing into existence a work environment that conformed to her sense of herself and her place in the world.

As the months passed, Katherine stretched out into the office, as at ease as if she had never been anyplace else. Erma Tynes, the other black computer who had been assigned with Katherine, was "by the book": at her desk and working at 7:59:59, barely removing her eyes from the task at hand until the end of the day at 4:30. Katherine, on the other hand, like the engineers around her, got into the habit of reading newspapers and magazines for the first few minutes of the day. She perused *Aviation Week*, trying to connect the dots between the latest industry advance and the torrent of numbers flowing through her calculating machine.

Katherine's confidence and the bright flame of her mind were irresistible to the guys in the Flight Research Division. There was nothing they liked more than brains, and they could see that Katherine Goble had them in abundance. As much as anything, they responded to her exuberance for the work. They loved their jobs, and they saw their own absorption reflected back at them in Katherine's questions and her interest that went so far beyond just running the numbers.

With her fair skin and dulcet West Virginia accent, Katherine might have occupied a fluid racial middle ground, easing her acceptance at the center. Even some of the black employees weren't always sure upon meeting her if she was black. On one occasion, when her mother was visiting from West Virginia, she'd had to take her to the hospital. After an unusually long wait, a doctor had to step in to get her mother

put into a room: the admitting desk was moving slowly because they couldn't figure out if she should have a black or a white roommate. One time Katherine's boss, Al Schy, was asked if his group had any black mathematicians. Even with Katherine sitting within earshot, he'd had to think before coming up with a yes. To her colleagues, she had become simply "Katherine."

For any number of reasons, concrete and ineffable, there was something about Katherine Goble that made her as comfortable in the office in 1244 as she was in the choir loft at Carver Presbyterian. She didn't close her eyes to the racism that existed; she knew just as well as any other black person the tax levied upon them because of their color. But she didn't feel it in the same way. She wished it away, willed it out of existence inasmuch as her daily life was concerned. She had taken the long road to Langley's Flight Research Division, but she knew with a confidence approaching 100 percent that she had arrived at the right destination.

"I want to move our girls out of the projects," Jimmy Goble said to Katherine after two years in Newport News.

Moving to Newsome Park had made it possible for Katherine and her family to adapt quickly to life in Hampton Roads. The neighborhood, with its ties to the shipyard and to Langley, with residents who were connected to virtually every aspect of black life in the region, had provided them and their family with a ready-made community. In defiance of the newspaper headlines, Newsome Park had managed to persevere against the ever-present specter of demolition: with the flare-up of military tensions in Korea in 1950, the federal Housing and Home Finance Agency again decided that Newsome Park and all similar housing projects were necessary to the country's ongoing defense effort. The residents of the neighborhood heaved a collective sigh of relief.

More than matters of international law at the 38th parallel, which divided Russian-allied North Korea from US-friendly South Korea, it was the local law of supply and demand that was really keeping New-

CHAPTER SIXTEEN

What a Difference a Day Makes

Well into her nineties, Katherine Goble would recall watching the winking dot of light in the sky as vividly as if it were still October 1957. She stood outside in the unseasonably warm autumn nights of that year and tracked the shiny pinpoint as it moved low across the horizon. Around Hampton Roads and throughout America, citizens turned their eyes skyward with a mixture of terror and wonder, eager to know if the 184-pound metal sphere launched into orbit by the Russians could see them as they tried to see it from their backyards. They surfed the radio dial trying to lock on to the artificial moon's beeping, its sound like an otherworldly cricket.

"One can imagine the consternation and admiration that would be felt here if the United States were to discover suddenly that some other nation had already put up a successful satellite." Those words from a letter describing a secret 1946 RAND Corporation proposal to the US Air Force, suggesting that the United States design and launch a "world circling satellite," sounded, in 1957, like the unheeded voice of Dickens' Ghost of Christmas Future. In the 1940s, space research was deemed a little too far out to warrant systematic consideration and development. The Rand report gathered dust.

Now, with Sputnik circling overhead every ninety-eight minutes, Americans demanded to know how their country, so dominant in its victory in the last war, could have been surprised and usurped by a "backward peasantry" like the USSR. Panic spread from coast to coast: was it possible that the satellite was mapping the United States, with the intent of locking down targets for missile-delivered hydrogen bombs? Fear battled humiliation in the American psyche. "First in space means first, period," declared Senate Majority Leader Lyndon Johnson. "Second in space is second in everything." Could Sputnik signal the end of the country's global political dominance?

In reality, the United States wasn't trailing the Soviet Union quite as badly as it appeared in the wake of the Sputnik crisis. The US Army's Jupiter-C missile had been tested successfully on several occasions, and the Americans were ahead of the Russians in terms of the systems that guided missiles on their trajectories into space. But President Eisenhower had insisted that the nation's first foray into space be presented as a peaceful effort, rather than an explicitly military operation that risked triggering a dangerous retaliation by the Soviet Union. The Americans had planned to launch the first satellite into orbit as part of the International Geophysical Year, a cooperative global science project that ran from July 1957 to December 1958. Physicists, chemists, geologists, astronomers, oceanographers, seismologists, and meteorologists from sixty countries, including the United States and the Soviet Union, collaborated to collect data and conduct earth science experiments, under the mantle of peaceful interchange between East and West. Trumped by Sputnik, the Americans played catch-up. The US Army's Jet Propulsion Laboratory successfully orbited the Explorer I satellite in January 1958. Two months later, Project Vanguard, managed by the US Naval Research Laboratory, also managed to launch a satellite, though the achievement was overshadowed by Vanguard's many rocket failures.

From where Katherine Goble was sitting, upstairs in Langley's hangar, the Soviet move looked rather like a new beginning for the NACA nuts. Skies all over the world bore witness to four decades of successful Langley research, from passenger jets to bombers, transport planes to fighter aircraft. With supersonic military aircraft a reality, and the

industry moving forward on commercial supersonic transport, it appeared that the "revolutionary advances for atmospheric aircraft" had run their course. Furthermore, Langley's high-speed flight operations, which had been migrating over the years from the populated Hampton Roads area to isolated Dryden, in the Mojave Desert, were officially ended by a 1958 NACA headquarters edict. As Katherine and her colleagues in the Flight Research Division wondered what was next, Sputnik provided them with the answer.

Space had long been a "dirty word" for the airplane-minded Langley. Congress admonished the brain busters not to waste taxpayer money on "science fiction" and dreams of manned spaceflight. Even in the Langley Technical Library, which was arguably the world's best collection of information on powered flight, engineers were hard-pressed to find books on spaceflight.

That didn't stop Langley engineers from imagining how the missile bodies and rocket engines and reentry problems involved in high-speed flight research might also apply to space vehicles. Any craft that traveled into space first had to traverse the layers of Earth's atmosphere, accelerating through the sound barrier and increasing numbers on the Mach speed dial, before escaping the pull of Earth's gravity and settling into the eighteen-thousand-mile-per-hour speed that locked objects into low Earth orbit, following a circuit of between 134 and 584 miles above the planet. On the return trip, the vehicle skidded through the friction of the increasingly dense atmosphere, building up heat that could reach 3,000 degrees Fahrenheit. NACA engineer Harvey Allen discovered, somewhat counterintuitively, that although the most aerodynamically streamlined shapes were best for slipping out of the atmosphere, a blunt body that increased rather than decreased air resistance was best for dissipating the extreme temperatures on the way back down.

With the US government desperate to gain a foothold in the space race, Langley now could open its garage door and display its wares for the world to see. A group that included Mary Jackson's division chief, John Becker, advocated for a vehicle that was capable of reaching orbital speeds and then gliding back down to Earth like a traditional aircraft, an advanced version of the X-15 rocket plane. It would be an elegant solution to the problem of space, they thought, one that made the hearts of the NACA's old-school "wing men" beat faster.

But the urgency of the competition with the Soviets created pressure to adopt the quickest, surest way into space, even if it was a little crude, or sacrificed long-term spacefaring viability for short-term earthly victory. In the Flight Research Division, Katherine Goble spent her days with her mind and her data sheets full of the specifications of real planes—not plane parts, not model planes, not disembodied wings in wind tunnels but actual vehicles that hurtled humans through the atmosphere. Flight Research's cousins, a "notoriously freethinking" group of engineers called the Pilotless Aircraft Research Division—PARD—had developed an expertise in rocketry, setting up an adjunct operation on an isolated test range on Wallops Island off the Virginia coast. Their rockets had reached speeds of Mach 15 in flight, and they were confident of their abilities to lift a payload—a satellite and a human passenger—into orbit.

As the clamor for action in space grew louder, engineers from PARD and the Flight Research Division moved to center stage. The core of the group coalescing around the US space effort shared an office with Katherine, ate sandwiches with her during lunch, and bonded with her over an enthusiasm for gust alleviation and wake turbulence. Virtually every history of the space program would include their names—John Mayer, Carl Huss, Ted Skopinski, W. H. Phillips, Chris Kraft, and others.

Katherine Goble had stood behind the engineers' numbers for the past three years, and as humans bounded beyond the sky she would continue to do so. Like many other Americans, Katherine bridled at the reality of the Russians' metal moon orbiting overhead. *We can't let that pass without doing something about it*, she thought. But beyond sating the national pride that had been pricked by the Soviet advance, the prospect of being involved in something that was so untried, untested, and unexplored connected with Katherine's truest self. Getting the chance to figure out how to send humans into space was fortune beyond measure. As she worked with the engineers to build a course from

the warmth and safety of their home to the cold void beyond, Katherine Goble's talents would truly take flight.

Dorothy Vaughan watched the furor from a second-floor office in the Unitary Plan Wind Tunnel, Building 1251. The Unitary Plan Tunnel had come online in 1955, funded by legislation to build state-of-the-art wind tunnels at each of the NACA's three main laboratories. The team that occupied most of the new building managed its own section of computers, like all the laboratory's divisions now.

Physically, Dorothy and the West Computing office had never been closer to the high-speed future. As the laboratory embraced the onset of the space age, the Unitary Plan Wind Tunnel would remain one of the busiest hubs of the center, testing "nearly every supersonic airplane, missile, and spacecraft" that saw the light of day over the next two decades. But in terms of the center's computing operations, Dorothy's pool now existed on the periphery. By 1956, more black women were now working in other areas of the laboratory than in West Computing itself. After more than a decade in their two-room spread in the Aircraft Loads Laboratory, Dorothy and the remaining women had been downsized to the new office in 1251. Miriam Mann, Ophelia Taylor, Chubby Peddrew, and many others from West Computing's class of 1943 had, like Katherine Goble and Mary Jackson, been offered permanent positions with engineering groups. Dorothy Vaughan was more likely to run into her former colleagues in the Langley cafeteria or the parking lot than to see them during the workday.

Dorothy had glimpsed the shadows of her own future when Langley disbanded the East Computing pool in 1947. Each new facility the laboratory built fueled the demand for specialization among its professionals. As the answers to the fundamental problems of flight became clearer, the next level of questioning required finer, more acute knowledge, making the idea of a central computing pool—generalists with mechanical calculating machines, capable of handling any type of overflow work—redundant. If anything, the NACA's response to Sputnik would only intensify the process of change, as the herculean task of safely navigating the heavens was divided into myriad smaller tasks, tests, parts, and people. Expertise in a subfield was the key to a successful career as an engineer, and expertise was becoming a necessity for the mathematicians and computers as well. Without it, women remaining in the segregated pool were left in a state of technical limbo.

Getting hired by the laboratory as a professional mathematician had been an important and groundbreaking stride for the black women—for all of Langley's women, of course. Their employment represented an expansion of the very idea of who had the right to enlist in the country's scientific workforce. From the beginning of the computing pools, the women easily hurdled the engineers' expectations, raising the bar as they did it. As the days of World War II receded into memory, so did the expectation that riveters and gas station attendants and munitions experts and, yes, even mathematicians would, or even should, be female. And yet, away from public view, one of the largest concentrations of professional female mathematicians in the United States stayed on the job, their identities wedded to their professions.

The defense machine's hunger virtually assured them of a job through retirement. Advancement, however, would require a different plan of attack. It was a concept easily grasped, empirically proven, but far from simple to execute: if a woman wanted to get promoted, she had to leave the computing pool and attach herself to the elbow of an engineer, figure out how to sit at the controls of a wind tunnel, fight for the credit on a research report. To move up, she had to get as close as she could to the room where the ideas were being created.

With East Area Computing gone, West Area Computing was boxed in on two fronts. Not only was the group all black, it was also the only stand-alone all-female professional section left at the laboratory, and by the late 1950s, that had become an anachronism. The black men, like Thomas Byrdsong and Jim Williams and Larry Brown, certainly had to spar with racial prejudice, but they started their Langley careers with all the privileges of being a male engineer. And although the lacunae of computing pools attached to PARD and Flight Research and the plethora of tunnels were also staffed and supervised by women, those

women, including the newly integrated black computers, reported directly to researchers, and they were closely tethered to the work and the status of the male engineers whose spaces they shared. Like Virginia Tucker before her, Dorothy Vaughan now presided over an appendix, still attached to the research operation but whose function had attenuated over time.

Dismantling East Computing had been a simple matter of operations, of supply and demand and expedience. When that pool's numbers grew too small to warrant maintaining a section, the laboratory simply distributed the stragglers into other sections and passed their outstanding assignments along to West Computing. But as long as "West Computer" was still the unspoken code for "Colored Computer," the decision to draw the curtain on Dorothy's group would require more nuanced consideration.

The progress that the black women had made in the last fourteen years was unmistakable. Demand for their mathematical abilities had opened Langley's front door to them, and the quality of their work had kept them at their desks. Through the familiarity that came with regular contact, they had been able to establish themselves not as "the colored girls" but simply "the girls," the ones engineers relied upon to swiftly and accurately translate the raw babble of the laboratory's fierce machines into a language that could be analyzed and turned into a vehicle that cut through the sky with grace and power.

True social contact across the races was well nigh impossible, yet within the confines of their offices, relationships cultivated over intense days and long years blossomed into respect, fondness, and even friendship. The colleagues exchanged Christmas cards with one another, asked after spouses and children. An engineer's wife gave Miriam Mann's daughter a shiny new penny to put in her shoe on her wedding day. The employees came together for extracurricular activities based at the laboratory: in 1954, Henry Reid appointed Chubby Peddrew to serve as one of the directors of Langley's inaugural United Fund Drive. The Activities Building was the site of club meetings and branch gettogethers, an end run around the embarrassment and difficulty of finding a venue in the town that would accommodate a racially mixed group. The Negro employees began attending centerwide events such as the annual Christmas party; one season, Eunice Smith volunteered as a Santa's helper. Every year, Dorothy Vaughan's children counted the days until the laboratory's giant picnic, where they could romp and play with the other kids and eat their fill of grilled hot dogs and hamburgers.

The social and organizational changes occurring at Langley were buoyed by the civil rights forces gathering momentum in the country. A. Philip Randolph, implacable in his advocacy of voting rights and economic equality, was actively working with younger organizers, principally the minister of a Montgomery, Alabama, church named Martin Luther King Jr. King and a fellow pastor named Ralph Abernathy had helped organize a boycott of the city buses after a fifteen-year-old student named Claudette Colvin and Rosa Parks, a forty-two-year-old seamstress, were both hauled off to jail for refusing to yield their seats in the "white" section of the bus. As with the legal case of Irene Morgan, the woman arrested in Virginia's Gloucester County in 1946 for the same infraction, the battle over integration on Montgomery buses eventually won a hearing in front of the Supreme Court. Once again America's highest court ruled segregation illegal. The controversy over the bus boycott vaulted the young Dr. King into the national headlines as the leader of the civil rights movement.

Langley Air Force Base and Fort Monroe moved forward to integrate the housing and the schools on their bases; as federal outposts, they were bound to comply with federal law. The state of Virginia, on the other hand, hoisted the Jim Crow flag even higher. In the years following the *Brown v. Board of Education* ruling, Senator Harry Byrd's antipathy toward the law had swelled into a countering movement—Massive Resistance—and he marshaled every resource at his political organization's disposal to build a firebreak against integration. Byrd Machine politician J. Lindsay Almond assumed the governorship and the party line in January 1958. "Integration anywhere means destruction everywhere," Almond inveighed in his inaugural address, his words a dark mirror of Lyndon Johnson's anxious commentary on Sputnik. Claiming to be the front line of defense for the entire South and its "way of life," the southern Democrats who ruled the state passed a package of laws that gave the legislature the right to close any public school that tried to integrate. "How can Senator Byrd and [Virginia] Congressman Hardy be so distressed one minute about our lagging behind the Russians in our missile program and the next minute advocate closing the schools in Virginia?" demanded one *Norfolk Journal and Guide* columnist.

Supporters of integration and segregation faced off with growing intensity: in 1956, the NAACP filed lawsuits in Newport News, Norfolk, Charlottesville, and Arlington, with the aim of forcing each of those Virginia school districts to integrate. The Byrd cronies retaliated by diverting taxpayer money to fund whites-only "segregation academies," private schools founded to circumvent integrated public schools. The no-go situation in the Virginia schools was evidence of just how difficult it was going to be to pull out the roots of the caste system that had defined and circumscribed virtually every interaction between whites and those considered nonwhite since the English first set foot on the Virginia coast. "While integration waits to be born, the 'separate but equal' education of the Negroes marks time," wrote journalist James Rorty in *Commentary Magazine*.

That so many West Computers managed to find opportunity as they rotated into new positions at the lab certainly relieved some of the pressure for Langley management to take a more active hand in the matter of integration. Langley might easily have continued its organic approach to desegregation, ending West Area Computing only after the last of the women had found a new home with an engineering section, like grade school kids waiting to be picked for a kickball team. Driven by the pragmatic sensibility of the engineers, management had naturally tacked toward a policy of benign neglect with respect to the bathroom signs and lunchrooms, neither enforcing compliance with the rules nor eliminating them altogether. It might have taken years longer before the unseen hand that had been vanquished by Miriam Mann in the lunchroom in the early 1940s would take the next step and pry the riveted aluminum COLORED GIRLS signs off Langley's bathroom doors. But by leapfrogging the United States into space, the Russians had turned even local racial policy into fodder for the international conflict. In forcing the United States to compete for the allegiance of yellow and brown and black countries throwing off the shackles of colonialism, the Soviets influenced something much closer to Earth, and ultimately more difficult than putting a satellite, or even a human, into space: weakening Jim Crow's grip on America.

"Eighty percent of the world's population is colored," the NACA's chief legal counsel Paul Dembling had written in a 1956 file memo. "In trying to provide leadership in world events, it is necessary for this country to indicate to the world that we practice equality for all within this country. Those countries where colored persons constitute a majority should not be able to point to a double standard existing within the United States." It would take a lot more than a shiny Soviet ball and the threat of international disdain to completely break the Byrd organization's commitment to racial segregation. As far as the segregationists were concerned, racial integration and Communism were one and the same and posed the same kind of threat to traditional American values. Yet those charged with mounting the American offense in space saw strength in countering the Russian value of secrecy with its opposites—transparency, democracy, equality—and not a simulacrum.

Though many competitors within the US government were vying to lead the space effort—among them the US Air Force, the US Naval Research Observatory in Washington, DC, and Wernher von Braun and the Germans who ran the Army Ballistic Missile Agency in Huntsville, Alabama—it was the NACA that was chosen as the repository for all of America's disparate space operations. The NACA—civilian and innocuous, abundant in engineering talent—was the perfect container. In October 1958, with Mother Langley as the nucleus, the US government fused all the competing operations, along with the Jet Propulsion Laboratory, into the NACA. The expanded mission called for a new name: the National Aeronautics and Space Administration, or NASA.

The NACA was quiet, obscure, and largely overlooked. NASA would be high-profile, high-stakes, and scrutinized by the world. The work done by the NACA nuts was hidden behind the more public operations of the military services and commercial aircraft manufacturers. NASA was chartered "to provide for the widest practicable and appropriate dissemination of information concerning its activities," with all failures and tragedies of the endeavor laid bare to the citizenry and broadcast through the influential young medium of television. With the world watching, the new organization carrying the American banner into space would have to be "clean, technically perfect, and meritocratic, the bearer of a myth."

The transition from the NACA to NASA didn't change Langley's facilities significantly, nor did it require drastic changes in the laboratory's staff. But the shift in attitude and in public responsibility at the laboratory were as distinct in character as the golden age of aeronautics of the 1950s would be from the space-age 1960s. The quirky place where upstart engineers competed to "bootleg" their own projects with the knowing wink of their supervisors, where a central laboratory had grown organically into a culturally cohesive organization of five thousand had, from October 1957 to October 1958, become a high-profile bureaucracy with ten research centers and ten thousand employees.

As the Space Act of 1958 made its way through Congress, trailing behind it the sheaves of legal documents and memoranda required to bring NASA to life, one memo quietly circulated at what was soon to be renamed the Langley Research Center, authored by Langley's assistant director, Floyd Thompson, dated May 5, 1958, officially ending segregation at Langley.

"Effective this date, the West Area Computers Unit is dissolved."

As the clock ticked down on the NACA, only nine West Computers remained in the pool: Dorothy Vaughan, Marjorie Peddrew, Isabelle Mann, Lorraine Satchell, Arminta Cooke, Hester Lovely, Daisy Alston, Christine Richie, Pearl Bassette, and Eunice Smith. With one terse line of text, NASA crossed a frontier that had not been breached by its predecessor. The memo heralded the end of an era, the swan song of the Band of Sisters. The story of West Area Computing—how Dorothy

Vaughan and her colleagues found their way to Langley, the tragedy and hope of World War II, the tyranny of the signs in the Langley cafeteria and on the bathroom doors, the women's contributions to one of the most transformative technologies in the history of humankind—would get passed along as family lore, but leave barely a fingerprint in the histories of the black men and women who fought for progress in their communities, of the women who pushed for equality for their gender in all aspects of American life, or of the engineers and mathematicians who taught humans to fly. For the rest of their lives, the former West Computers reminisced with one another and with the East Computers and the engineers they worked with. They told tales at the retirement parties that crowded their calendars in the 1960s and 1970s and 1980s, but with the modesty characteristic of women of their generation, they were reluctant to describe their achievements as anything more than "just doing their jobs."

The end of the West Area Computing section was a bittersweet moment for Dorothy Vaughan. It had taken her eight years to reach the seat at the front of the office. For seven years after that she ruled the most unlikely of realms: a room full of black female mathematicians, doing research at the world's most prestigious aeronautical laboratory. Her stewardship of the section had supported the careers of women like Katherine Goble, who would ultimately receive her country's highest recognition for her contributions to the space program. The standards upheld by the women of West Computing set a floor for the possibilities of a new generation of girls with a passion for math and hopes for a career beyond teaching. Just as the original NACA-ites would forever hold on to their identities as members of that venerable organization, the black women would always feel an allegiance to West Area Computing, and to the woman who led it to its final day, Dorothy Vaughan.

Dorothy was forty-eight years old in October 1958, with more than a decade of work still stretching out before her. Her older children, so tiny when she had first come to Hampton Roads, were now entering college. The younger boys were adolescents following fast in the path of their older siblings. Her work at Langley had enabled her to make good on her promise to her children and their futures. With their educations on track and a house of her own in her name—the Vaughans also left Newsome Park, in 1962—there was nothing stopping Dorothy from making the final years of her career about her own ambitions.

"She was the smartest of *all* the girls," Katherine Goble would say of her colleague, years into her own retirement. "Dot Vaughan had brains coming out of her ears" (and Katherine Goble knew from brains). Dorothy was proud of the way she had navigated through the days of racial segregation, proud of whatever small share she might claim in contributing to the demise of that backward practice. She had watched the women of West Computing, along with the others at the laboratory, take flight within the NACA's research operations; together, they proved that given opportunity and support, a female mind was the analytical equal of its male counterpart. But despite knowing for many years that this day would eventually come, and having done everything within her power to bring it about, the victory she savored as the memo circulated was tempered with disappointment. Progress for the group meant a step back for its leader; Dorothy's career as a manager came to an end on the last day of the West Area Computing office.

Dorothy had never been one to linger over the past; the decade waiting in the wings promised to be one of the most interesting ever witnessed at the laboratory. For better or worse, Langley's fresh start was giving Dorothy Vaughan a fresh start as well. She would now begin life at the new agency as she had started her career at the NACA: as just one of the girls.

CHAPTER SEVENTEEN

Outer Space

"This is not science fiction," wrote President Eisenhower, in the preface to a fifteen-page document entitled *Introduction to Outer Space*. Prepared by the President's Advisory Committee on Science in March 1958 as a primer on spaceflight, the brochure laid out the scientific principles of travel beyond the Earth's atmosphere in terms a layperson could understand. "As everyone knows, it is more difficult to accelerate an automobile than a baby carriage," read one passage. It also made the case for why a space program—and its enormous price tag—was in the interest of every American, offering four arguments for the public's consideration. National defense and global prestige, of course, were the two concerns that had moved the reverie of space travel from the purview of novelists and eccentrics to the country's number-one priority. The only thing that rivaled Americans' fear of the Soviet Union's incipient prowess in the heavens was their wounded national pride.

Thirdly, space exploration would bring an unprecedented opportunity to expand the body of human knowledge about the universe, prompted the pamphlet. Sputnik launched smack in the middle of the International Geophysical Year, and experts around the world fantasized over the cornucopia of data that might be harvested by a satellite or solar system–faring probe, a mechanical, electrical proxy for their own inquisitive eyes.

Katherine Goble certainly acknowledged the value of those three rationales, but for her, it was the one listed on the first page of the brochure that resonated most: humans pined to go into space because of their longing to know what lay beyond the confines of their own small world; they desired to leave Earth out of a compelling urge to go where no human had gone before. Katherine had always been driven by curiosity, and as the activity in and around Building 1244 crescendoed, it consumed her. Eisenhower's brochure put forth a vague, practically useless timetable for when the United States might be expected to achieve a variety of objectives in space: "Early," "Later," "Still Later," "And Much Later Still." The real schedule—and no one knew this better than the people in Building 1244—was As Soon As Humanly Possible. *When* America should venture beyond the confines of Earth was just as obvious as *why*. But *how*? That was what Katherine Goble ached to know.

She was far from alone. The plan for planting the American flag in the heavens, and the decision regarding who would lead the charge, was the table topic at Wright-Patterson Air Force Base in Ohio, at Wernher von Braun's Army Ballistic Missile Agency in Alabama, and at the Naval Observatory in Washington, DC. Officials gathered around conference tables at the NACA headquarters and at each of the NACA laboratories, concerned with plotting the quickest possible path into space. Nowhere vibrated with more anticipation than Langley. Katherine Johnson's deskmates—John Mayer, Ted Skopinski, Alton Mayo, Harold "Al" Hamer, Carl Huss—moved from one meeting to another, conferring with each other, with their bosses, with representatives of aircraft manufacturers and military services, turning to every possible source in order to aggregate intelligence for the still inchoate endeavor.

The only real reference that the Langley brain busters could lay their hands on was *Introduction to Celestial Mechanics*, a 1914 textbook by Forest Ray Moulton. So the engineers, who knew more about flying vehicles than any others, began scaling the next learning curve. Katherine's branch chief, Henry Pearson, organized a "self-education" lecture series that began in February 1958 and lasted through May, drafting individual engineers in Flight Research and PARD to present on one of seventeen topics related to space technology. Even in the early, confusing months after Sputnik, the top engineers in those divisions, with decades of experience in flight-test research (and many with a not-so-secret love of science fiction) sensed that they were on the cusp of a once-in-a-lifetime opportunity. They threw themselves into the class. John Mayer tackled orbital mechanics, Al Hamer lectured on rocket propulsion, and Alton Mayo handled reentry, the problems faced by an object returning to Earth. Carl Huss taught the physics of the solar system. Ted Skopinski was the trajectories guy, elaborating on the math describing the path taken by a space vehicle as it left Earth's surface and settled into orbit around it.

Katherine Goble had fallen in love with her job at Langley virtually the moment she walked through the door of West Computing. The four years she had spent doing monotonous calculations on gust alleviation had only intensified the desire to drain every drop of knowledge she could from the engineers she worked with. With the transmutation of her division's priorities from aeronautics to space, however, her work was taking a particularly toothsome turn. Massaging the Monroe calculator and filling out the data sheets, which grew longer and wider as the work became more intricate, would still be part of her daily duties. But the engineers in the group now assigned her the job of preparing the charts and equations for the well-received space technology lectures. It was like a bell sounding, taking her back to the course on the analytic geometry of space that Dr. Claytor had created for her. Claytor's demanding, rapid-fire instruction had laid the foundation both for the content of the work at hand and for its intensity. That preparation was critical as she put the abstract three-dimensional Cartesian plane to use in the service of the space technology lectures, which were eventually compiled in written form. It was the textbook of space the *place*, being written in real time.

Katherine listened carefully to everything the engineers said, strained for snippets of conversation, and devoured *Aviation Week* like a kid reading the funny papers. The real action, she knew, was taking place there in the lectures and editorial meetings, those closed-door sessions where engineers subjected preliminary research reports to the same relentless scrutiny and stress testing that they applied to the aircraft they engineered. Her interest in the proceedings of the meetings increased in direct proportion to her proximity to them. By the measure of the rest of the country, she was an insider's insider. She enjoyed a front-row seat at a spectacle that the rest of the citizenry learned about in the daily newspaper and on the nightly news. But however close she sat to the room where the meetings took place, she was still an outsider if she couldn't get in the door.

Building an airplane was nothing compared to shepherding research through Langley's grueling review process. "Present your case, build it, sell it so they believe it"—that was the Langley way. The author of a NACA document—a technical report was the most comprehensive and exacting, a technical memorandum slightly less formal—faced a firing squad of four or five people, chosen for their expertise in the topic. After a presentation of findings, the committee, which had read and analyzed the report in advance, let loose a barrage of questions and comments. The committee was brusque, thorough, and relentless in rooting out inaccuracies, inconsistencies, incomprehensible statements, and illogical conclusions obscured by technical gibberish. And that was before subjecting the report to the style, clarity, grammar, and presentation standards that were Pearl Young's legacy, before the addition of the charts and fancy graphics that reduced the data sheet to a coherent, visually persuasive point. A final report might be months, even years, in the making.

Katherine sat down with the engineers to review the requirements for the space technology lectures and the research reports that were starting to come out of the process. She listened closely to their instructions and, as was her habit, she asked questions. Not just questions designed to clarify the marching orders she had been given, but the kind of queries she had fired at her parents and teachers as a child, meant to broaden and deepen her understanding of how things work so she could create a more refined model of the world. Why did the trajectory equation need to account for the oblateness of Earth? Why was it necessary to calculate an error ellipsoid to accurately predict the satellite's return to the planet's surface?

She had asked plenty of questions when the scope of her work had extended only from the nose cone of a tiny Cessna 405 to its tail fin. Now there was so much more to ask, so much more to understand, and because it was all new, she felt like she was right there on the learning curve with the engineers. As the work intensified, something that had been hibernating in her mind awakened, and once roused it would not go away. She considered the issue and checked its logic, just as she did with her analytical work. At first she asked it only of herself, but eventually she came to the engineers with the question.

"Why can't I go to the editorial meetings?" she asked the engineers. A postgame recap of the analysis wasn't nearly as thrilling as being there for the main event. How could she not want to be a part of the discussion? They were her numbers, after all.

"Girls don't go to the meetings," Katherine's male colleagues told her.

"Is there a law against it?" Katherine retorted. There wasn't, in fact. There were laws telling her where she might answer nature's call—a law she ignored at Langley—and which fountain to drink from. There were laws restricting her ability to apply for a credit card in her own name, because she was a woman. But no law applied to the editorial meeting. It wasn't personal: it was just the way things had always been done, they told her.

Restricting the computers from joining the editorial meetings wasn't a rule: it was a rule of thumb. It was rooted in practice and widely implemented, but it did not apply without exception to every situation. Langley gave each division chief, and every branch head and section head below them on the ladder, a certain amount of leeway in the management of their groups. Whether or not a woman was promoted, if she was given a raise, if she had access to the smoky sessions where the future was being conceived and built, had much to do with the prejudices and predilections of the men she worked for.

In 1959, six of Langley's female employees—Lucille Coltrane, Jean Clark Keating, Katherine Cullie Speegle, Ruth Whitman, Emily

Stephens Mueller, and Dorothy Lee—assembled around a table in a Langley office to sit for a group photo, their elegant, well-made suits amplifying the confidence in their gaze. "Women Scientists," the photographer labeled the picture, though the particulars of the occasion would be lost to the passage of time. They had rated inclusion in the photograph because of some combination of rank, research contributions, and general esteem in the eyes of their bosses. Five out of the six women in the photo worked in PARD.

One of the women in the photo, Dorothy Lee, had accepted a position as a computer in PARD in 1948, fresh out of Randolph-Macon Women's College in Virginia, just after East Computing was disbanded. When branch chief Maxime Faget's secretary took off for a two-week honeymoon, Dorothy was asked to sub for her. She answered the phones and distributed the mail in addition to her regular duties, which at the time involved solving a triple integral for an engineer in the division. At the end of the two weeks, she had so impressed Faget with her math (not her secretarial skills, as she didn't know how to type) that he invited her to become a permanent member of his branch, apprenticing her to men who showed her the ropes of aerodynamic heating. By 1959 she had authored one report, coauthored seven more, including one with Max Faget, and, like Mary Jackson, been promoted to engineer.

Early in her career at Langley, Dorothy Lee was interviewed for the *Daily Press*, in all probability by Virginia Biggins, the female reporter assigned to the Langley beat. "Do you believe," she was asked, "that women working with men have to think like a man, work like a dog, and act like a lady?" "Yes, I do," Lee said, who was then mildly mortified to read her words in the Sunday paper.

It was the "acting like a lady" term of the equation that was so vexing. A little bit of coyness, like wormwood, could be pleasantly intoxicating, smoothing interactions with the men. Too much politesse, however, might poison a woman's prospects for advancement. Women were "supposed" to wait for the assignments from their supervisors, and weren't expected to take the lead by asking questions or pushing for plum assignments. Men were engineers and women were computers; men did the analytical thinking and women did the calculations. Men

gave the orders and women took notes. Unless an engineer was given a compelling reason to evaluate a woman as a peer, she remained in his blind spot, her usefulness measured against the limited task at hand, any additional talents undiscovered.

Some women did indeed spend their days in rote service to the day's task, plotting data with blithe indifference, routing torrents of numbers as nonchalantly as the calculating machines they cradled. But the average level of interest in the work among female employees was no lower than it was for their male counterparts, the "inveterate wind tunnel jockeys" and the mediocre "can't-hack-it engineers" who managed to carve out a comfortable place for themselves in the bureaucracy despite modest talents or ambition. For the women who had found their true calling at the NACA, like Dorothy Lee, like Katherine Johnson, they woke up dreaming of angles of attack and two-body orbit equations and ablation processes no less than did Chris Kraft and Max Faget and Ted Skopinski. They matched their male colleagues in curiosity, passion, and the ability to withstand pressure. Their path to advancement might look less like a straight line and more like some of the pressure distributions and orbits they plotted, but they were determined to take a seat at the table. First, however, they had to get over the high hurdle of low expectations.

Whatever personal insecurities Katherine Goble might have had about being a woman working with men, or about being one of the few blacks in a white workplace, she managed to cast them aside when she came to work in the morning. The racism stuff, the woman stuff: she managed to tuck all that way in a place far from her core, where it would not damage her steely confidence. As far as Katherine was concerned—as far as she had *decided*—once they got to the office, "they were all the same." She was going to assume that the smart fellas who sat across the desk, with whom she shared a telephone line and the occasional lunchtime game of bridge, felt the same. She only needed to break through their blind spots and make her case.

"Why can't I go to the editorial meetings?" Katherine Goble asked again, undeterred by the initial demurral. She always kept up the questioning until she received a satisfactory answer. Her requests were gentle but persistent, like the trickle of water that eventually forces its way through rock. The greatest adventure in the history of humankind was happening two desks away, and it would be a betrayal of her own self-confidence and of the judgment of everyone who had helped her to reach this point to not go the final distance. She asked early, she asked often, and she asked penetrating questions about the work. She asked with the highest respect for the natures of the brainy fellas she worked with, and she asked knowing that she was the right person for a task that needed the finest minds.

As much as anything, she asked with confidence in the ultimate decision.

"Let her go," they finally said, exasperated. The engineers just got tired of saying no. Who were they, they must have figured, to stand in the way of someone so committed to making a contribution, so convinced of the quality of her contribution that she was willing to stand up to the men whose success—or failure—might tip the balance in the outcome of the Cold War?

In 1958, Katherine Goble finally made it into the editorial meetings of the Guidance and Control Branch of Langley's Flight Research Division, soon to be renamed the Aerospace Mechanics Division of the nearly-ready-for-prime-time National Aeronautics and Space Administration. Now, she was going to come along with the program.

CHAPTER EIGHTEEN

With All Deliberate Speed

1958 was a year no Langley employee would ever forget. Leaving work on September 30, they said good-bye to the National Advisory Committee for Aeronautics, the esoteric operation that for forty-three years had quietly supervised and directed the airpower revolution, good-bye to the Langley Aeronautical Laboratory of yore. On the morning of October 1, the former NACAites walked into the Langley Research Center, epicenter of the National Aeronautics and Space Administration, a new American agency whose birth had been induced by a hurtling Soviet sphere. The buildings hadn't changed, nor had the people, or, for many of them, the work they were charged with. But from sundown one day to sunup the next, they had gone, if only in the public imagination, from erudite and obscure to obvious and spectacular, from the crackpots of the airplane epoch of the 1940s to the guardians of the space-age 1960s.

At the end of the 1950s, when the American space program looked as uncoordinated and spindly as a foal, predicting that the United States would best the Soviets might have seemed like a fool's bet. NASA had other plans, creating a brain trust at Mother Langley called the Space Task Group, a nimble, semi-autonomous working group that drew largely from the Flight Research Division and PARD and was led by engineer Robert Gilruth. The Space Task Group set up shop on Langley's East Side in some of the laboratory's oldest buildings. Those space pilgrims, an initial group of forty-five people, gave the country's first manned space program an operating plan and a name: Project Mercury. The venture had three goals: to orbit a named spacecraft around the Earth, to investigate man's ability to function in space, and to recover both men and spacecraft safely.

Virginians puffed out their chests with pride now that the good old brain busters were leading the charge against the Reds. An October 1959 open house at Langley held on the occasion of NASA's first anniversary attracted twenty thousand ardent locals eager for an up-close look at the work of the unusual neighbors they had underestimated and overlooked for decades. No longer just a "a dull bunch of gray buildings with gray people who worked with slide rules and wrote long equations on blackboards," NASA, the public now believed, was all that stood between them and a Red sky. However, Virginia's legacy as the birthplace of humanity's first step into the heavens would have to compete with the notoriety it was gaining as the country's most intransigent foe of integrated schools.

"So far as the future histories of this state can be anticipated now, the year 1958 will be best known as the year Virginia closed the public schools," lamented Lenoir Chambers, editor in chief of Virginia Beach's *Virginian-Pilot* and a southern liberal in the mold of Mark Etheridge of the *Louisville Post-Courier*. Undeterred and unchastened by the 1957 showdown in Little Rock, the Byrd Machine's Massive Resistance movement made good on its threat. In the fall of 1958, Virginia's governor Lindsay Almond chained the doors of the schools in localities that attempted to comply with the Supreme Court's *Brown* decision. Thirteen thousand students in the three cities that had moved forward with integration—Front Royal, Charlottesville, and Norfolk—found themselves sitting at home in the fall of 1958. "I would rather have my children live in ignorance than have them go to school with Negroes," one white parent told a reporter. A total of ten thousand of the shut-out students lived in Norfolk: 5,500 of those from military families stationed

at the naval base, white students as well as black paying the price for the state's racial crusade.

Across the water from Norfolk, on the peninsula that Langley called home, public schools remained open but segregated. Even as the barriers in their parents' workplace continued to erode, the children of Langley's black employees returned to their fall routines at Carver, Huntington, and Phenix, while their white colleagues' children went back to Newport News High and Hampton High. In their new home in Mimosa Crescent, the Goble daughters were now zoned to attend Hampton High School. The school board, however, paid "school fees" to the families as an incentive for them to keep their children in the black district, similar to the out-of-state "scholarships" the state offered to black graduate students to keep them from integrating Virginia colleges.

The forces in favor of equality redoubled their efforts, determined to surmount the resistance to integration like a jet engine propelling an airplane through drag. But, like Christine Darden and everyone else whose hopes—and fears—had escalated on the day the *Brown* case was decided, blacks in Virginia were acutely aware of the long lag between legal and political triumphs and social change. As fantastical as America's space ambitions might have seemed, sending a man into space was starting to feel like a straightforward task compared to putting black and white students together in the same Virginia classrooms.

Rather than trying to make plans based on machinations beyond their reach, parents like Dorothy Vaughan, Mary Jackson, and Katherine Goble worked hard to influence what they did control: pushing their children to excel in their segregated schools and getting them into college. Katherine Goble's eighteen-year-old daughter, Joylette, a talented violinist and a graceful beauty, graduated salutatorian of Carver High School's class of 1958 and headed across town to attend Hampton Institute. Connie and Kathy, honor students and musicians in Carver High's sophomore class, nipped at their elder sister's heels. The girls and their mother made regular appearances in the social column of the *Norfolk Journal and Guide*, the model of an upwardly mobile and professional black family.

In public, Katherine Goble was unfailingly gracious, optimistic, and unflappable, and she insisted that her girls acquit themselves in the same fashion. Her grief and loneliness, the burden of being both mother and father, she relegated to the privacy of their house on Mimosa Crescent. Jimmy Goble had been the love of Katherine's youth, a nurturing father, and the partner she expected to grow old with. The two of them had been a compatible, attractive, and charming couple, making the rounds of the black community's fall galas, debutante balls, picnics, and fund-raisers. As a single woman, still youthful at forty years old, she found herself drifting toward the social sidelines.

Eunice Smith was Katherine's steadfast companion and confidante. The two of them spent more time together than many married couples, commuting back and forth to work each day, serving together as officers of the Newport News chapter of their sorority, AKA, taking time off from work to root for their teams in the yearly Central Intercollegiate Athletic Association (CIAA) basketball tournament for black colleges. They never missed Sunday service at Carver Memorial Presbyterian Church, and one night a week when they left Langley they headed over to Carver for choir practice.

One evening in 1958, a handsome thirty-three-year-old army captain with a ready smile and a rich bass voice ambled into practice. James A. Johnson, born in rural Suffolk, Virginia, had moved with his family to Hampton as an adolescent. He attended Phenix High School, and in fact Mary Jackson had been one of his student teachers. Jim Johnson had planned to attend Hampton Institute but was drafted right after graduating from high school. Rather than being assigned to the US Naval Training School there on the campus, he was sent to the US Navy Boot Camp in Great Lakes, Illinois. He trained in aviation metalsmithing, specializing in the repair of propellers. After his war service, Johnson finished his degree and landed a clerk job at the Commerce Department in Washington, DC, but he also signed up for the US Navy Reserve so he could spend his weekends at Patuxent River Naval Base in Maryland, repairing planes used for test flight. With the onset of the Korean War, he enlisted in the army, serving as an artillery sergeant, calibrating guns being fired on enemy infantry. In 1956, he returned to

Hampton, taking a job at the post office as a mail carrier, maintaining his trim military shape through miles of walking each day. Never one to stray too far from the armed services, he also signed up as a member of the US Army Reserve.

"Ladies, he's single," the pastor had announced in church that Sunday after introducing Jim as a new member of the congregation. It hadn't been Katherine's expectation or intention to find a new love, but almost immediately after meeting in the choir loft, she and Jim began courting, tentatively turning up together at dances and dinner parties and arriving together at church as a family, with Kathy and Connie in tow.

Jim's devotion to the military service made it easy for him to understand Katherine's strong commitment to her work at Langley. He knew the satisfaction that came from fulfilling employment and loved the sense of mission and camaraderie that the military gave him. As a black man, he relished the opportunity to step forward from the cook and steward and laborer jobs that had traditionally been reserved for blacks and gain expertise in an area where he felt he could make a frontline contribution.

He was also sensitive to the secretive nature of Katherine's work and the longer hours her job now demanded of her. Since the end of World War II, the NACA had been an eight-to-four-thirty kind of place. Now, at the outset of the space race, leaving the building at ten o'clock would be a good night. In a less urgent scenario, NASA personnel might have taken a more NACA-like approach to the problem of space by conducting a careful, measured investigation of all possible options for space travel and recommending the ones with the greatest long-term potential. There were those within NASA who believed, and would continue to believe for decades into the future, that the government's decision to put all its chips on a short-term strategy to beat the Soviets came at the cost of the opportunity to turn humans into a truly spacefaring species. With the Russians off to what looked like a commanding lead, it was the simplest, fastest, and most reliable approach that began to take shape as NASA teased out the limitations, interdependencies, contingencies, and unknowns they faced. The engineers approached Project

Mercury the way engineers tackled any problem: they broke Project Mercury down into its constituent parts.

The spacecraft itself, the can that would take a man into space, was the brainchild of Dorothy Lee's boss, Maxime Faget. Aerodynamic theory and intuition suggested that the rocket and spacecraft combination should be as streamlined as possible, to minimize aerodynamic drag. Since the Wright Brothers' 1915 Flyer, airplanes had evolved from pelican-like awkwardness to sleek machines with the silhouette of a falcon; why wouldn't a spaceship continue along that same path? But tests by Harvey Allen, an engineer at the NACA's Lewis Flight Propulsion Laboratory in Cleveland, showed that needle-shaped structures wouldn't be able to deflect the extreme heat caused when they zoomed through the friction of the atmosphere. A blunt-shaped body—something shaped more like a champagne cork—would create a shock wave as it came back toward Earth, dissipating the heat and keeping (they hoped) the man inside safe. Faget put Allen's insight to work in the design of the Mercury space capsule, six feet wide and nearly eleven feet long, weighing three thousand pounds.

The selection process for astronauts would be limited to candidates small enough to fit into the lunchbox of a spaceship: only men at or under five feet, eleven inches tall and weighing less than 180 pounds were considered. Each was required to be a qualified test pilot under forty years old with at least a bachelor's degree. In 1959, NASA held a press conference to present the "Mercury Seven" astronauts to the world. Four of the seven selected—Alan Shepard, Scott Carpenter, Wally Schirra, and John Glenn—had graduated from the US Naval Test Pilot School at Patuxent River, where Katherine's new beau, Jim Johnson, had worked as a mechanic. NASA installed the astronauts in an office at Langley next door to the Space Task Group and proceeded to put them through physical training and classroom instruction in engineering and astronautics. Employees stayed alert to catch a glimpse of the Mercury Seven, who had gone from anonymous military men to among the most recognizable faces in the world. Computers working in the Space Task Group and the astronauts, whose office was located in

the same building, often ran into each other going to and coming from the bathrooms.

The rockets NASA needed to blast spacemen and spacecraft into space would come from the army's existing inventory of Redstone and Atlas missiles, overseen by Wernher von Braun at NASA's Marshall Space Center in Huntsville, Alabama. The propulsion experts at NASA's laboratory in Cleveland took the lead on the craft's electrical system and the retrofire rockets built into the craft itself.

To the engineers on Katherine's desk fell the responsibility of the trajectories, tracing out in painstaking detail the exact path that the spacecraft would travel across Earth's surface from the second it lifted off the launchpad until the moment it splashed down in the Atlantic. As the head of the Space Task Group, Robert Gilruth had been given his pick of NASA employees to fill the ranks of Project Mercury's nerve center. Katherine's office mate, John Mayer, had jumped ship for the new endeavor a week after it was created, in November 1958. The workload generated by Project Mercury was so onerous that even after Mayer transferred from 1244 to the offices on the East Side, he "bootlegged" the overflow work to his old buddies Carl Huss and Ted Skopinski, getting them to help out with whatever time they could squeeze in around what they owed to Henry Pearson. He got them to do "computing runs" for him—which meant getting Katherine to do computing runs for them. The group took on the additional tasks with zeal, because space looked like "a hell of a lot of fun." They turned their desks into a trigonometric war room, poring over equations, scrawling ideas on blackboards, evaluating their work, erasing it, starting over.

There was virtually no aspect of twentieth-century defense technology that had not been touched by the hands and minds of female mathematicians. Like Katherine and her colleagues at Langley, women at the Aberdeen Proving Ground in Maryland spent thousands upon thousands of woman-hours computing ballistics trajectory tables, which soldiers used to accurately calibrate and fire their weapons, as Jim Johnson had in Korea. The first attempt to put a man into space, NASA decided, should be a simple ballistic flight, with the capsule fired into space by a rocket like a bullet from a gun or a tennis ball from a tennis ball machine. Capsule goes up, capsule comes down, its path defined by a big parabola, its landing place the Atlantic Ocean. The astronaut needed to return near enough to waiting navy ships to be quickly hoisted out of the water and pulled to safety. The challenge was to rig the machine's position so that the ball—the Mercury capsule—landed as closely as possible to the navy's waiting racket. Calculated incorrectly, the ball would go out of bounds, the astronaut's life endangered. The math had to be as precise and accurate as an Althea Gibson serve.

A well-executed suborbital flight would buy the United States a little breathing room; but orbital flight—the end game of Project Mercury—was infinitely more complex. Successful orbital flight required the engineers to adjust the tennis ball machine's chute to the correct angle and arm its launcher with enough force to send the ball up through the atmosphere and into an orbit around Earth on a path so precisely specified, so true, that when it came back down through the atmosphere, it was still within spitting distance of the navy's waiting racket.

"Let me do it," Katherine said to Ted Skopinski. Working with Skopinski as a computer (or "math aide," as the women had been renamed when the NACA became NASA), she had proven herself to be as reliable with numbers as a Swiss timepiece and deft with higher-level conceptual work. She was older than many of the space pilgrims, some of whom were just out of college, but she matched them at every turn for enthusiasm and work stamina. The fellas were putting everything they had on the line, and she was not going to be left out. "Tell me where you want the man to land, and I'll tell you where to send him up," she said.

Her grasp of analytical geometry was as good as that of the guys she worked with, perhaps better. And the unyielding demands of Project Mercury and the sprawling, still-forming organization that was being built to manage it stretched everyone to the limit. Soon after John Mayer put on the Space Task Group jersey, Carl Huss and Ted Skopinski followed suit, making Katherine the natural inheritor of the research report that would describe Project Mercury's orbital flight. As

had been the case many other times in her life, Katherine Goble was the right person in the right place at the right moment.

Sitting in the emptier office, she plunged into the analysis, although the pesky laws of physics turned an afternoon of rote celestial tennis practice into a forces free-for-all. Earth's gravity exerted its force on the satellite and had to be accounted for in the trajectory's system of equations. Earth's oblateness—the fact that it was not perfectly spherical but slightly squat, like a mandarin orange—needed to be specified, as did the speed of the planet's rotation. Even if the capsule were to shoot off into the air directly overhead and come back down in the same straight line, it would land in a different spot, because Earth had moved.

"In the recovery of an artificial earth satellite it is necessary to bring the satellite over a preselected point above the earth from which the reentry is to be initiated," she wrote. Equation 3 described the satellite's velocity. Equation 19 fixed the longitude position of the satellite at time T. Equation A3 accounted for errors in longitude. Equation A8 adjusted for Earth's west-to-east rotation and oblation. She conferred with Ted Skopinski, consulted her textbooks, and did her own plotting. Over the months of 1959, the thirty-four-page end product took shape: twenty-two principal equations, nine error equations, two launch case studies, three reference texts (including Forest Ray Moulton's 1914 book), two tables with sample calculations, and three pages of charts.

The rapidly growing Space Task Group was taking shape as an autonomous unit marching out in front of the space parade. The new endeavor consumed as many person-hours as it could be given. Even as the Space Task Group worked to create boundaries with the research center that had given birth to it, Space Task Group employees still had responsibilities to their old managers. Katherine's and Ted Skopinski's Azimuth Angle report was the work of the Flight Research Group, the responsibility of their branch chief, Henry Pearson, and while Ted Skopinski was increasingly out of sight, spending time over at the STG offices on the East Side, the report, still unfinished, was not out of Henry Pearson's mind.

"Katherine should finish the report," Skopinski said to Pearson. "She's done most of the work anyway." Henry Pearson had the reputation of being less than supportive of the advancement of female employees, but whether it was circumstance, the triumph of hard work over bias, or an incorrectly deserved reputation, it was on his watch that Katherine put the finishing touches on her first research report on the Friday after Thanksgiving 1959. "Determination of Azimuth Angle at Burnout for Placing a Satellite over a Selected Earth Position" went through ten months of editorial meetings, analysis, recommendations, and revisions before publication in September 1960—the first report to come out of Langley's Aerospace Mechanics Division (or its predecessor, the Flight Research Division) by a female author. Stepped on, turned out, pulled apart, and subjected to every stress test the editorial committees could throw at it, Katherine's road map would help lead NASA to the day when the balance of the space race was tipped in favor of the United States.

For Katherine, the report commemorated the beginning of a new phase not just at Langley but in her personal life. Somehow, during the long, bleary-eyed days of 1959, she accepted an offer even more enticing than being invited into the editorial meetings: Jim Johnson's marriage proposal. The two married in August 1959 in a quiet ceremony at Carver Memorial. When she signed her first research report, she used a new name, the name that history would remember: Katherine G. Johnson.

CHAPTER TWENTY

Degrees of Freedom

In February 1960, as NASA pushed forward with reliability tests on the Mercury capsule, four students from North Carolina Agricultural and Technical, a black college in Greensboro, North Carolina, sat down at the segregated lunch counter in the town's Woolworth's and refused to move until they were served. The following day, the "Greensboro Four" had become a group of twenty activists. On the third day, sixty students converged upon the Woolworth's, and by the fourth, three hundred had joined the demonstration. Participating were students from Bennett College, an all-black women's college in Greensboro, as well as white students from Guilford College and the Women's College of the University of North Carolina. Within a week, the protests, inspired by the nonviolent actions of India's Mahatma Gandhi, spread to other cities in North Carolina, and then crossed the borders into Kentucky, Tennessee, and Virginia. The students started calling their protests "sit-downs" or "sit-ins." The prison sentences that often attended their activism did nothing to quell their ardor. "Dear Mom and Dad: I am writing this letter tonight from a cell in the Greensboro jail. I was arrested this afternoon when I went into a lily-white lunch room and sat down . . ." wrote a young Portsmouth woman who attended North Carolina A&T. Like a match on dry kindling, the sit-ins set aflame Negroes' smoldering, long-deferred dream of equality with a speed and intensity that took even the black community by surprise.

Hampton Institute was the first school outside of North Carolina to organize a sit-in. On the campus, many students had come into contact with one of the early icons of a mobilization that seemed to be gaining national momentum. Five years earlier, Rosa Parks, the Montgomery, Alabama, seamstress and NAACP member, refused to yield her seat on a city bus to a white man, galvanizing the bus boycott led by Martin Luther King Jr. and Ralph Abernathy. A ferocious backlash against Parks ensued: she received death threats, and both she and her husband, Raymond, were blacklisted from employment in Montgomery. The president of Hampton Institute reached out to Parks, offering her a job as a hostess at the university's faculty dining room, the Holly Tree Inn. Parks accepted, arriving on campus in 1957 and working at the restaurant into 1958.

When the sit-ins came to Hampton, Christine Darden was an eighteen-year-old Hampton Institute junior carrying a double course load. Her father had insisted that she earn a teaching certificate as a backup plan for her pursuit of a career in the sciences. Christine found herself captivated by the incipient activist movement, and despite carrying a full semester of courses in math and physics and extra classes in teacher education, she found time to join the protests, which eventually swelled into marches of more than seven hundred. Students walked across the Queen Street Bridge to downtown Hampton and converged on the lunch counters at Woolworth's and Wornom's, the local drug store. They quietly occupied the stores, some sitting at tables reading and working on homework assignments, until the owners shut down their establishments in the middle of the afternoon. The next month, five hundred students staged a peaceful protest through downtown Hampton. An outspoken group of thirteen movement leaders held a press conference with local newspapers. "We want to be treated as American citizens," they told the reporters. "If this means integration in all areas of life, then that is what we want."

Christine also decided to join the voter registration drives organized at Hampton, walking door-to-door in black neighborhoods

along Hampton's Shell Road and Rip Rap Road, imploring black voters to register in time to make their voices heard in the November 1960 presidential showdown between the Republican, Vice President Richard Nixon, and the Democrat, Senator John F. Kennedy of Massachusetts.

Despite its unyielding advocacy of Negro economic empowerment, Hampton Institute's stance on integration had always been of the go-slow variety, wartime president Malcolm MacLean being a notable exception. Now, with a black president at the helm for the first time, even Hampton succumbed to the zeitgeist of the era. Dorothy Vaughan's eldest daughter, Ann, who had left Hampton Institute in 1957, returned in the fall of 1959 to finish her degree. The campus she came back to was alive, breathless even, with the possibility of significant and permanent social change. One rumor that spread like wildfire through the network of energized students—a rumor that seemed wholly improbable, but which took root until it was accepted as fact—was that the astronauts were contributing to the students' organizing activities. The astronauts represented everything that mainstream America held dear—*and they're with us*, the students marveled. The very *idea*, that those buzz-cut middle-American boys were standing, however surreptitiously, with the Negro student activists! The fact that the rumor couldn't be confirmed did nothing to dampen its power. At the beginning of a decade when everything was beginning to seem possible, nothing seemed impossible.

If anyone could bear witness to the long-term impact of persistent action, and also to the strength of the forces opposing change, it was Dorothy Vaughan. Virginia's governor, Lindsay Almond, capitulated, reopening Norfolk, Charlottesville, and Front Royal schools in 1959 and inching toward integration: eighty-six black students in those districts now attended school with whites. In Prince Edward County, however, segregationists would not be moved: they defunded the entire county school system, including R. R. Moton in Farmville, rather than integrate. No municipality in all of America had ever taken such draconian action. As white parents herded their students into the new segregation academies, the most resourceful black families scrambled to salvage their children's educations by sending them to live with relatives around the state, some as far afield as North Carolina. Prince Edward's schools would remain closed from 1959 through 1964, five long and bitter years. Many of the affected children, known as the "Lost Generation," never made up the missing grades of education. Virginia, a state with one of the highest concentrations of scientific talent in the world, led the nation in denying education to its youth. Dorothy's friends and former Moton colleagues watched helplessly as their children's futures were sacrificed in the battle over the future of Virginia's public schools. Commenting on the situation in 1963, United States Attorney General Robert Kennedy said, "The only places on earth known not to provide free public education are Communist China, North Vietnam, Sarawak, Singapore, British Honduras—and Prince Edward County, Virginia."

Meanwhile, Langley moved in the opposite direction. When Dorothy Vaughan turned off the lights in the West Area Computing office for the last time, she and the remaining women in the segregated pool were dispatched to the four corners of the laboratory, finally catching up to colleagues who had already found permanent positions in an engineering group. Marjorie Peddrew and Isabelle Mann went to Gas Dynamics, Lorraine Satchell and Arminta Cooke joined Mary Jackson in the Supersonic Tunnels Branch, Hester Lovely and Daisy Alston left for the Twenty-inch Hypersonic Jets Branch, Eunice Smith went to Ground Loads, and Pearl Bassette was assigned to the Eleven-inch Hypersonic Tunnel.

As for the West Computers' erstwhile leader, Dorothy Vaughan found herself in a new seat in another brand-new building. In 1960, Langley had only just completed Building 1268, a West Side facility housing one of the most advanced computer complexes on the East Coast. Electronic computing had moved from the wings of aeronautical research to the main stage. Accordingly, Langley centralized its computing operations into a group named the Analysis and Computation Division, created to service all the center's research operations, as well as to provide computing to outside contractors. The ACD organization chart was a snapshot of two decades of change at Langley. Dorothy was reunited with many of her West Computers, but they now

worked side by side with East Computing alumni like Sara Bullock and Barbara Weigel.

Perhaps more striking than the racial integration of the female mathematicians, which had been spreading organically throughout Langley for years, was the fact that a group focused on computing now employed increasing numbers of men. The function of computing had been promoted from an all-female service organization with minimal hardware requirements to a top-level division with an eight-figure operating budget; it was starting to look a lot more like a launchpad and a career path to ambitious young men. The room-sized machines were remaking the old models of aeronautical research; their ascendance marked the beginning of an era that promised to be even more momentous than the one ushered in by the flying machine. For better or worse, it also signaled the beginning of the end of computing as women's work.

Some of the older women at the center, the ones who still relied upon the mechanical calculators, were starting to look as if they were stranded on an island, separated from the mainland by a gulf that grew wider each year. The early 1960s were an inflection point in the history of computing, a dividing line between the time when computers were human and when they were inanimate, when a computing job was handed off to a room full of women sitting at desks topped with \$500 mechanical calculating machines and when a computing job was processed by a room-sized computer that cost in excess of \$1 million.

Dorothy Vaughan was keenly aware of that undulating invisible line that separated the past from the future. At fifty years old and many years into her second career, she reinvented herself as a computer programmer. Engineers still made the pilgrimage to her desk, asking for her help with their computing. Now, instead of assigning the task to one of her girls, Dorothy made a date with the IBM 704 computer that occupied the better part of an entire room in the basement of Building 1268, the room cooled to polar temperatures to keep the machine's vacuum tubes from overheating.

In the past, Dorothy would have set up the equations in a data sheet and walked one of her girls through the process of filling it out. At

ACD, it was her job to convert the engineers' equations into the computer's formula translation language—FORTRAN—by using a special machine to punch holes in $7\frac{3}{8}$"×$3\frac{1}{4}$" cards printed with an array of eighty columns, each column displaying the numbers 0 through 9, each space assigned a number, letter, or character. Once punched, each cream-colored card represented one set of FORTRAN instructions.

The longer or more complex the program, the more cards the programmer fed the computer. The machines tapped out at two thousand cards—two thousand lines of instructions. Even modest programs could require a tray of hundreds of the cards, which needed to be fed into the computer in the correct order. Woe to the klutz who dropped a box of cards on the floor. Some programmers tried to forestall disaster by taking a Magic Marker and painting a big diagonal swath on the top surface of a vertical stack of cards, a continuous line from the front corner on the first card to the opposite back corner of the final card, hoping that the tiny dot of color on each would provide the key to reassembling the fumbled cards into the correct order.

As powerful as ACD's computer was, however, the maestros of Project Mercury would require even more electronic horsepower for what was to come next. At the end of 1960, NASA purchased two IBM 7090s and installed them in a state-of-the-art facility in downtown Washington, DC, managed by the Goddard Space Flight Center, a Greenbelt, Maryland, NASA field center opened in 1959 to focus exclusively on space science. The agency set up a third computer, a slightly smaller IBM 709, in a data center in Bermuda. Together the three computers would monitor and analyze all aspects of the spaceflights, from launch to splashdown.

The planned suborbital flights presented a controlled set of challenges. Taking off from Cape Canaveral, Florida, and landing in the Atlantic at a spot approximately fifty miles from Turks and Caicos, the hurtling capsule would remain within communications range of Mission Control in Florida and the data centers in DC and Bermuda. Orbital flights—which sent the astronaut on one or more ninety-minute circuits around the globe, passing out of visual and radio contact with Mission Control, flying over unfriendly territory—upped the ante by

a factor. Constant contact with the astronaut during every minute of every orbit was a prerequisite for the flight.

The task of building a worldwide network of tracking stations that would maintain two-way communication between the orbiting spacecraft and Mission Control fell to Langley. Langley put all available resources behind the $80 million project in 1960, putting the final pieces in place just before December 1960, the originally scheduled date for the first suborbital mission. The Mercury tracking network in and of itself was a project whose scale and boldness rivaled that of the space missions it supported. The eighteen communications stations set up at measured intervals around the globe, including two set up on navy ships (one in the Atlantic Ocean, another in the Indian Ocean), used powerful satellite receivers to acquire the radio signal of the Mercury capsule as it passed overhead. Each station transmitted data on the craft's position and speed back to Mercury control, which bounced the data to the Goddard computers. The "CO3E" software program, developed by the Mission Analysis branch and programmed into the IBM computers, integrated all the equations of motion that described the spacecraft's trajectory, ingested the real-time data from the remote stations, and then projected the remaining path of the flight, including its final splashdown spot. The computers also sounded the alarm at the first sign of trouble; any deviation from the projected flight path, evidence of malfunction on board the capsule, or abnormal vital signs from the astronaut, which were also being monitored and transmitted to doctors on the ground, would send Mission Control into troubleshooting mode.

The launch date for Project Mercury's first manned mission slipped into 1961, a year that announced itself as unpredictable from the start: on January 3, the United States cut diplomatic relations with Cuba, another step down the road in the Cold War with the Soviet Union. President Dwight Eisenhower, in his farewell speech in January 1961, railed against the United States' growing military-industrial complex. On March 6, 1961, President John F. Kennedy, newly inaugurated, announced Executive Order 10925, ordering the federal government and its contractors to take "affirmative action" to ensure equal opportunity for all of their employees and applicants, regardless of race, creed, color, or national origin. Through it all, the Space Task Group, the Langley Research Group, the other NASA centers, and thousands of NASA contractors pressed forward on their aerodynamic, structural, materials, and component tests, closing in on a target launch date in May.

"We could have beaten them, we should have beaten them," Project Mercury flight director Chris Kraft recalled decades later. In the midst of America's high hopes for redemption in the heavens, the Soviets struck again. On April 12, 1961, Russian cosmonaut Yuri Gagarin became in one fell swoop the first human in space and the first human to orbit Earth. Unlike the disorientation, anxiety, and fear that Sputnik provoked, the agency absorbed the blow. It was painful, certainly, and embarrassing as well, but they turned the welter of emotion into renewed intensity for the mission, employing all of their talents and the principles of math, physics, and engineering to create a precise and thorough plan. Now they executed it with the knowledge that there was only one direction to move: forward.

It would take a total of 1.2 million tests, simulations, investigations, inspections, verifications, corroborations, experiments, checkouts, and dry runs just to send the first American into space, a precursor to achieving Project Mercury's goal of placing a man into orbit. Every mission involved the Mercury capsule, though the rockets—Scout, Redstone, and Atlas—varied. Mercury-Redstone 1, or "MR-1," the first mission to mate the Mercury capsule to the Redstone rocket, failed on the launchpad. MR-2, with Ham the chimpanzee as its passenger, overshot the landing spot by sixty miles and was nearly underwater when it was finally plucked from the ocean. Pulling back the curtain on three and a half years of work, NASA took the audacious step of deciding to broadcast the launch of Project Mercury's first manned mission—"Mercury-Redstone 3," carrying astronaut Alan Shepard—live. Forty-five million Americans would tune in to witness the ultimate success or failure of MR-3. When Shepard finally strapped into the disarmingly small capsule—just six feet in diameter and six feet, ten inches high—

and rode the Redstone candle into space, reaching an altitude of 116.5 miles above Earth, it was a resurrection for the United States and a much-needed dose of adrenaline for NASA.

The suborbital flight in the capsule Shepard christened Freedom 7 lasted only fifteen minutes and twenty-two seconds and covered 303 miles, just about the distance between Hampton, Virginia, and Charleston, West Virginia. Freedom 7 was a pale technical achievement compared to Yuri Gagarin's flight the month before, but its success emboldened President Kennedy to pledge the country to a goal significantly more ambitious: a manned mission to the Moon.

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth," President Kennedy said before a session of Congress, not three weeks after Shepard splashed down. Every NASA employee involved with the space program, still burning the midnight oil working on Project Mercury, broke out in a cold sweat. The agency hadn't yet achieved its mandate to place a human into orbit, and Kennedy already had them kicking up Moon dust?

It was a terrifying prospect—and the most exhilarating thing they had ever heard. Unspoken publicly until that moment, getting to the Moon, one of mankind's deepest and most enduring dreams, had long been the private dream of many at Langley as well. But with only one operational success under its belt and with six Mercury missions to go—with the orbital flight still on the drawing board—NASA's road to the Moon seemed unimaginably complex. The engineers estimated that the upcoming orbital flight, including the fully manned global tracking network, required a team of eighteen thousand people. The buildup to a lunar landing would demand many times more people than could be reasonably supported by Mother Langley.

The whispered rumors now gained currency: the Space Task Group's time in Hampton was coming to an end. The Langley employees, and the locals, campaigned with all their might to keep their brainchild from leaving home. Geography and politics had smiled on Virginia in 1915, when the NACA first went searching for its proving ground and aeronautical laboratory. As it had in the period leading up to World

War I, the federal government made a list of possible sites for the headquarters for its space effort, looking for the right combination of climate, available land, and friendly politicians. In 1960, nine locations made the short list, but Virginia was not one of them. Due in no small part to the influence of powerful Texans, including now Vice President Lyndon Johnson, NASA decided to move the heart of its space program to Houston. Many of the Langley employees—the former NACA nuts, including Katherine Johnson—were going to have to make hard choices. They had come to love their home by the sea, from the abundant fresh seafood to the mild winters to the water that surrounded the lonely finger of land that had become such a part of them. Soon, they knew, following the president's lead into space might mean choosing between the place that had given them a community and the passion for the work that gave their life meaning.

Over in Building 60 on Langley's East Side, Katherine's former colleagues Ted Skopinski, John Mayer, Carl Huss, and Harold Beck, who led the Mission Analysis branch within the rapidly growing Space Task Group, prepared for the move to Houston. Mary Shep Burton, Catherine T. Osgood, and Shirley Hunt Hinson, the math aides who ran the trajectory analysis software on the group's IBM 704, also decided to go. Unless more Langley women volunteered to make the move, the members of the branch worried that their new office "was going to be badly understaffed" just as the workload skyrocketed.

Katherine Johnson had been asked to transfer to Houston with the group, but her husband, Jim, wanted them to stay close to their families. Resisting Houston's call, not following the nerve center of the space program across the country, was difficult for Katherine and many of her Langley colleagues. It was "impractical" to recruit the mathematicians they needed in Virginia, so Mary Shep Burton and John Mayer went to Houston to recruit "five qualified young women" to come to Langley for training before setting up a permanent new computing pool in the under-construction "Manned Spacecraft Center." The move echoed the establishment of the first computing pool at Langley twenty-five years before.

The residents of Building 1244 might have been staying put in Hampton, but despite their concerns, much work remained for them on Project Mercury. Alan Shepard's flight was a triumph. MR-4, Virgil Grissom's July 1961 suborbital flight, came and went in a flash.

NASA's first orbital mission, and the debut of the all-important tracking and communications network, shimmered in the near distance like a heat mirage. Katherine and Ted Skopinski had laid out the fundamentals of the orbital trajectory nearly two years earlier, in their important Azimuth Angle report, then handed off the responsibility for the calculation of the flight launch conditions to the IBM computers. Like Dorothy Vaughan, Katherine Johnson knew that the rest of her career would be defined by her ability to use the electronic computers to transcend human limits. But before she crossed completely to the world of electronic computing, Katherine Johnson would tackle one last, very important assignment, using the techniques and the tools that belonged to the human era of computing. Like her fellow West Virginian John Henry, the steel-driving man who faced off against the steam hammer, Katherine Johnson would soon be asked to match her wits against the prowess of the electronic computer.

EPILOGUE

It's the question that comes up most often when I tell people about the black women who worked as mathematicians at NASA: Why haven't I heard this story before? At this point, more than five years after I first began the research for what would become *Hidden Figures*, I've fielded the question more times than I can count. Most people are astonished that a history with such breadth and depth, involving so many women and linked directly to the twentieth century's defining moments, has flown below the radar for so long. There's something about this story that seems to resonate with people of all races, ethnicities, genders, ages, and backgrounds. It's a story of hope, that even among some of our country's harshest realities—legalized segregation, racial discrimination—there is evidence of the triumph of meritocracy, that each of us should be allowed to rise as far as our talent and hard work can take us.

The greatest encouragement along the way has come from black women. All too often their portrayals—our portrayals—in history are burdened with the negative imagery and vulnerability that come from being both black and female. More disheartening is how frequently we look into the national mirror to see no reflection at all, no discernible fingerprint on what is considered history with a capital *H*. For me, and I believe for many others, the story of the West Computers is so electrifying because it provides evidence of something that we've believed to be true, that we want with our entire beings to be true, but that we don't always know how to prove: that many numbers of black women have participated as protagonists in the epic of America.

Katherine Johnson's passion for her work was as strong during the remainder of her thirty-three-year career at Langley as it was the first day she was drafted into the Flight Research Division. "I loved every single day of it," she says. "There wasn't one day when I didn't wake up excited to go to work." She considers her work on the lunar rendezvous, prescribing the precise time at which the lunar lander needed to leave the Moon's surface in order to coincide and dock with the orbiting command service module, to be her greatest contribution to the space program. But another set of her calculations stood at the ready during the 1971 Apollo 13 crisis, when the electrical system of the spacecraft carrying astronauts Jim Lovell, Jack Swigert, and Fred Haise was crippled by an onboard explosion, making it impossible to run the guidance computer as programmed.

An astronaut stranded hundreds of thousands of miles from Earth is like a mariner from a previous age, adrift in the most remote part of the ocean. So what do you do when the computers go out? This was precisely the question Katherine and her colleague Al Hamer had asked in the late 1960s, during the most intense preparations for the first Moon landing. And in 1967, Johnson and Hamer coauthored the first of a series of reports describing a method for using visible stars to navigate a course without a guidance computer and ensure the space vehicle's safe return to Earth. This was the method that was available to the stranded astronauts aboard Apollo 13.

Before the crisis was over, however, even Katherine and Al's backup calculations would require a backup: from inside the spaceship, the glinting debris field from the damaged capsule was indistinguishable from the actual stars, making the method specified in Katherine's report impossible to use. Astronaut Jim Lovell used an even simpler calculation to tack his spaceship toward home, lining up the ship's optical sight with Earth's terminator, the line dividing the side of Earth that was in daylight from the shadow side, in nighttime. It was serendipitous that Lovell had taken the technique for a test run on Apollo 8 and knew how to make the calculations. What seemed like a routine check on a previous mission would save the crew's lives this time around. No one knew better than Katherine Johnson that luck favored the prepared.

Katherine Johnson worked with Al Hamer and John Young for the rest of her years at Langley, developing aspects of the space shuttle and the Earth resources satellite programs. But it is Katherine's connections to the most glorious and glamorous days of the space program that brought her to the public's attention. Every year since 1962, when John Glenn took to orbit, acclaim for Katherine Johnson's achievement grew. The black press—the *Norfolk Journal and Guide*, the *Pittsburgh Courier*, the *Amsterdam News*, *Jet Magazine*—embraced her even before John Glenn left Earth. Of NASA, *Amsterdam News* editor James Hicks wrote: "They are loud in their praise of a young West Virginia–born Negro girl who has prepared a science paper that was not only a key document in the flight of Commander Shepard into outer space but which will actually become 'THE' key document if and when we are able to put an astronaut into orbit." Over time, articles began to appear in the peninsula's *Daily Press* and in the *Richmond Times-Dispatch*, and Katherine's name became a necessary entry in any book detailing the accomplishments of black or female (or black female) scientists and engineers. Since the 1960s, she has been invited into classrooms to inspire students with the stories of how mathematics has defined her life. In recent years she has become too fragile to make the trips to visit students; on August 26, 2016, she will be ninety-eight years old. Now the students come to her, making pilgrimages to see her in the retirement residence where she lives. Her contributions to the space program's signature epoch earned her NASA Group Achievement Awards for Project Apollo and the Lunar Orbiter Project. She has received three honorary doctorates and a citation from the state of Virginia. And a charter high school in North

Newsome Park, there was dwindling evidence of the hopefulness that Eric Epps had displayed when he dedicated the development's community center in 1945. The spaceflight revolution had solidified Katherine Johnson's and Dorothy Vaughan's positions in the middle class, but the neighborhood they and Eunice Smith and many others left behind was more and more like a poor island, cut off from the jobs and schools that would help them make the same leap the West Computers had made.

And that was before getting to "pollution, ecological damage, energy shortages, and the arms race," the gremlins of the century's technological revolution. Instead of creating unifying hope, an expansive space program was "salt on the wounds of the country's more Earth-bound concerns," wrote NASA historian Robert Ferguson. As early as 1966, President Johnson, the space program's biggest political champion, began looking at NASA as a "big fat money pot" that he could drain to ease a budget strapped by social programs and Vietnam. With the Moon landing achieved, the victory over the Soviet Union in hand, there was no urgency to push beyond Project Apollo, whose last two missions narrowly escaped cancellation.

The press surrounding the end of the Apollo program was clamorous, but the cancellation of another program also garnered headlines. In 1972, the United States decided to cancel its supersonic transport program, the SST, which many aerodynamicists had hoped would give them an "Apollo moment," a glorious, high-profile display of their technology. The expensive program raised the hackles of those concerned about its negative impact on the Earth's ozone layer, but it was the sonic boom "carpet" that swept across the landscape as the plane passed overhead that really inflamed public opinion. Reports claimed that shock waves from the high-speed commercial planes were "frightening residents, breaking windows, cracking plaster, and setting dogs to barking." Some purported that the invisible menace had even caused the "death of pets and the insanity of livestock." Local authorities received complaints of broken windows and traumatized animals, and calls to police surged as citizens reported unidentified blasts that came literally out of the clear blue sky.

The supersonic and hypersonic transport machines dreamed up in

the 1950s and 1960s would have to wait, although in the 1970s Langley did turn much of its focus back to NASA's first *A*: aeronautics. "In 1969 alone, there were 57 certified American airlines, which carried approximately 164 million originating passengers and some 20 billion revenue ton-miles of freight," NASA revealed in a 1971 publication. The aerodynamicists' priorities for the new decade were less glamorous, but a necessary part of solving the problems that were the result of an increasingly mobile society. One of the problems that the center focused on was noise abatement: busy skies were often noisy skies, even without sonic booms. Another issue was efficiency. With increasing fuel prices, the aircraft industry shifted its priority from increasing speed and power to boosting efficiency in subsonic or low supersonic flight.

Langley announced a sweeping reorganization in 1970, decreasing its workforce to a total of 3,853 from its peak of 4,485 employees in 1965. For those who lived through the reorganization, announced in the form of a forty-seven-page avocado-green book that landed on employees' desks at the end of September that year, it was in many ways a more jarring time than the period of transition from the NACA to NASA. Waves of RIFs and RIGs—Reductions in Force and Reductions in Grade—happened so frequently at Langley in the 1970s that they spawned a new verb, as in "John got riffed last week." Those who did survive the RIFs felt a sense of betrayal at NASA's significantly reduced ambitions. Not only were the brain busters not heading to Mars and the outer planets, but by December 1972, they had left their final footprints on the Moon. The summit of humanity's knowledge crashed into low-orbit reality. The NASA of the 1970s was interested in "routine, quick-reaction and economical access to space." The agency would never return to the glory of the Apollo years. But despite the downsizing of everything—budgets, workforce, expectations—the will to explore the world beyond Earth's atmosphere did not, would not, could not go away.

Mary Jackson managed to surf Langley's turmoil even as the sections, branches, and divisions around her recombined with greater frequency, the work groups at the bottom of the organization chart transforming like shards in a great NASA kaleidoscope. The names changed—Compressibility, Aero-Thermo, Applied Theory, Large Supersonic Tunnels, Transonic Aerodynamics, High-Speed Aircraft, Subsonic-Transonic—but her partnership with Kazimierz Czarnecki remained a constant. She stayed focused on the research she had pursued since becoming an engineer in 1958: the investigation of the impact of roughness (such as rivets or grooves) on the surface of a moving object on the boundary layer, that thin layer of air that passes most closely over a moving object. Never one to miss an opportunity to continue her education, Mary took FORTRAN classes, teaching herself to program. The computers that had made long-distance spaceflight possible were also revolutionizing aeronautical research, a specialty known as computational fluid dynamics. The engineers now conducted experiments in their beloved wind tunnels and then compared the results with simulations on their computers. Just as the electronic machines had taken the place of human computers in aeronautical research, the day would eventually come when the computer would displace the wind tunnel itself.

Mary Jackson was a tireless promoter of science and engineering as a meaningful and stable career choice. She made so many speeches at local schools that one might have thought she was running for office: Thorpe and Sprately Junior High Schools, Carver and Huntington High Schools, Hampton Institute, Virginia Wesleyan, a small college in Norfolk. At the King Street Community Center, where Mary had worked as the USO secretary during World War II, she started an after-school science club for junior and senior high school students. She helped the students build a smoke tunnel and conduct experiments, and taught them how to use the tool they created to observe the airflow over a variety of airfoils. "We have to do something like this to get them interested in science," Mary commented in a 1976 article in the employee newsletter *Langley Researcher*, which profiled her for being honored as the center's Volunteer of the Year. "Many times, when children enter school they shun mathematics and science during the years when they should be learning the basics."

In 1979, Mary Jackson organized the retirement party for Kazimierz Czarnecki, who was leaving government service after forty years.

Two years prior, the facility that had been the bedrock of most of their work—the four-by-four-foot Supersonic Pressure Tunnel, the third member of Mary and Kaz's partnership—had come to the end of its service at Langley as well. In 1977, the tunnel that had been state-of-the-art technology when it began operations in 1947 was razed to make way for the National Transonic Facility, a 1.2 Mach, $85 million tunnel that was powered by cryogenic nitrogen.

It was a moment for Mary to reflect on her career. She traveled regularly to make presentations at industry conferences, and by the end of the 1970s she had twelve authored or coauthored papers to her name. She had progressed from computer to mathematician to engineer, and in 1968 had been promoted to the level of GS-12. The budget cuts and RIFs of the 1970s made promotions harder to come by, however, and the next rung on the ladder for Mary Jackson—GS-13—was starting to look distant. GS-13 was a significant threshold, with few women in Langley at that grade in the mid-1970s. This was a contrast with Goddard, where both Dorothy Hoover and Melba Roy had hit the GS-13 mark by 1962. In 1972, NASA's agencywide goal was "to place a woman in at least one of out of every five vacancies filled at levels GS-13 through GS-15." The numbers of women, professional and administrative, had grown along with Langley's general level of employment, but women were still a scarcity in high-level technical positions and in management. Even seemingly small barriers conspired to keep larger numbers of women from advancing: until 1967, the Langley Field golf course—as in other workplaces, a prime location for networking—restricted women to playing during the workday, rather than allowing them to golf alongside men after work.

In 1979, Mary Jackson was fifty-eight years old and coming to the conclusion that she had probably hit the glass ceiling. It would have been easy for her to reap the benefits of seniority, reducing her workload and taking a long coast toward retirement. Even if the next promotion eluded her, she still had the prestige of being an engineer and the satisfaction of knowing how hard she had worked to arrive at this point. But a position opened up in the Human Resources Division, and Mary's name was floated to fill it: Federal Women's Program Manager, charged with pushing for the advancement of all of the women at the center. To relinquish her hard-won title of engineer, at an organization that was created and run by engineers, was no easy choice.

Mary's career frustration wasn't unique, she knew. When she looked around, she saw many women and minorities at Langley trapped in the sticky middle grades, unable to rise to the level that their ability would otherwise merit. Did Langley really need one more GS-12 aeronautical engineer, even if the seat was occupied by a black woman? Or would the center be better served by someone who could help make way for legions of employees, at every level and from every background, liberated to give their best to their work? Mary Jackson wasn't wired to take the easy road or be satisfied with the status quo. If the decision wasn't simple, it was certainly clear. Stepping off the engineering track wasn't a sacrifice if it allowed her to act on her principles. Taking a demotion from GS-12 to GS-11 in order to accept the less-prestigious position, Mary Jackson threw herself in 1979 into her new role as the center's Federal Women's Program Manager.

Helping girls and women advance was at the core of Mary's humanitarian spirit; she saw the relationships between women as a natural way to bridge racial differences. She had been instrumental in bringing the separate regional white and black Girl Scout Councils together into a unified service organization for all girls in southeastern Virginia. In 1972, Mary volunteered as an equal opportunity employment counselor, and in 1973 she joined Langley's Federal Women's Program Advisory Committee. Both programs had been created in the 1960s to make sure that the federal government was hiring and promoting without differentiation by race, gender, or national identity. At Langley, as in other federal workplaces, the programs had a beneficial secondary effect: they gave female and minority employees a formalized way to make connections and boosted their centerwide visibility. Mary had always been a natural networker, bringing people together to help one another and to marshal their support for the many causes that were dear to her heart. She became an energetic member of a group of Langley

women who were determined to push for opportunities for women of all colors at NASA, clearing the way for women to take their place as equals alongside men in science and engineering jobs, and also looking for ways to help secretaries and clerical employees to make the leap into technical jobs and program management. Accepting the position as the Federal Women's Program Manager was a way of uniting twenty-eight years of work at Langley with a lifetime commitment to equality for all.

One of the most difficult aspects of writing a book is knowing that there's not enough space or time to give voice to all the incredible people you meet along the way. The original draft of *Hidden Figures* had a final section portraying in detail how Mary Jackson and her fellow travelers went to all lengths in the 1970s and 1980s to extinguish the lingering traces of what NASA historian Sylvia Fries called the "fantasy that men were uniquely gifted to be engineers." Like Mary, the final narrative stepped away from the daily routines of research to follow the women of Langley as they formed alliances and used all the ingenuity they brought to engineering to change the face of the center's workforce. Making the decision to trim this section was difficult; while it allowed for the chance to spend more time with Dorothy, Mary, and Katherine in the golden age of aeronautics and space, it meant ending the book before Mary's decision to leave engineering for Human Resources. It also meant saying good-bye to one of my favorite "characters" in this sweeping drama, who has become a treasured friend in real life: Gloria Champine. The relationship between Gloria and Mary, which grew out of Mary's decision to sacrifice her engineering career for the future career prospects of other women, is one of the most poignant of all the stories I uncovered in the research.

Gloria Champine was born at Fort Monroe in Hampton in 1932, her family home a stone's throw from Mary's. Her father was an airman at Langley Field who was instrumental in the development of the parachute. He died in the crash of a Keystone bomber on a flight from Langley in 1933. Her stepfather was the crew chief on the only XB-15 ever built, which was stationed at Langley. Gloria spent part of her childhood on the base, where "everybody's daddy had a plane." She grew up overhearing her stepfather and his crew tell stories of the "crazy things" the NACA nuts put them through in order to analyze the flying qualities of their experimental model bomber. Gloria, who is white, graduated from Hampton High School in 1947, completed an associate's degree at a local business college, and found a job as the secretary to the head of a printing company in Newport News. In 1959, Gloria took the civil service exam and accepted a job as a secretary in the Mercury range office, helping with the logistics required to build the worldwide tracking network that debuted with John Glenn's orbital flight.

In 1974, an equal opportunity program gave Gloria the chance to advance from a clerical position in the Dynamic Loads Division into a faster-track administrative position in the Acoustics Division. Then, she competed for an even higher position as the Technical Assistant to the Division Chief of Space Systems, a job that had previously only been held by men. She went through the interview process three times, and each time she came out on top. "They kept testing you because they didn't want to give the position to a woman," a friend in Human Resources confided to her. Eventually, however, the center was obligated to hire Gloria: the best candidate for the job, the first woman in the position.

When Mary and Gloria were girls in the early part of the twentieth century, only the most gifted seer could have predicted the changes that would bring their paths together. In later years, Mary would describe to Gloria the segregation she had experienced in the early years at Langley. They met through one of the Federal Women's Program committees and became friends, collaborators, and conspirators in the service of a shared belief in helping unrecognized talent get its day in the sun. Like Mary, Gloria Champine had a "hard head and strong shoulders and back." She couldn't keep herself from acting when she saw a way to give someone else a leg up. She always kept an extra women's blazer behind the door in her office, in case a potential job candidate needed a little sartorial sharpening to make a better impression. When a young black woman who spent the summer interning with her mentioned an interest in computers, Gloria marched her over to meet the head of

a programming branch in the Business Systems Division. The young woman secured a place in a programmer trainee program.

Male supervisors warned Gloria to "stay away from the woman stuff," but the woman stuff was just as important to Gloria as it was to Mary Jackson. She had seen how dependent her mother, who was smart but valued for her beauty, had been on her father and stepfather. Gloria vowed never to be in the same situation; she never entertained the idea of not working, even after her three children came along. It was a decision that helped her to bear up when she separated from and then divorced her husband in the mid-1960s, leaving her a single mother and the head of her household at a time when the majority of white women still didn't work outside the home.

In 1981, Langley sent Mary Jackson to NASA headquarters in Washington, DC, for a year of training to become an equal opportunity specialist. Mary had already decided who should follow her as Langley's Federal Women's Program Manager. Though Gloria didn't come from a technical background, her military upbringing and fifteen years of experience at NASA gave her an understanding of the business of engineering and the motivations of the engineers. She knew airplanes better than a lot of the engineers she worked with. She was also a quick study with computers: Mary Jackson taught her how to "reprogram" the computers in the Human Resources Division, going deep into the databases that fed the systems in order to run statistical reports on employee qualifications and promotions. These reports revealed that female graduates with the same degrees as men were still more often hired as "data analysts," the upgraded term for the center's mathematicians, than as engineers. Black employees with similar qualifications lagged their white counterparts in promotions and were more likely to be steered to support roles, such as work in the Analysis and Computation Division, where Dorothy Vaughan had been reassigned, than to engineering groups. She showed Gloria how lacking a single course on a college transcript, such as Differential Equations, could keep an otherwise qualified and well-reviewed woman from keeping up with her male counterparts, even years after she had entered the workforce.

For the next five years, Mary Jackson and Gloria Champine were an effective social engineering team within the Equal Opportunity and Federal Women's Program offices. For three of those five years, they worked for my father, Robert Benjamin Lee III, a research scientist in Langley's Atmospheric Sciences Division. My father's move into equal opportunity was part of a career development program designed to "season" him for moves into management when he returned to his division.

Mary, however, spent the rest of her career in the equal opportunity office, retiring in 1985. Her husband, Levi Jackson Sr., had spent the end of his working years at Langley as well, transferring from the air force base in the 1980s, still working as a painter. "We always thought it was so cool that Grandma worked in the wind tunnels and Granddaddy painted them," remembered their granddaughter, Wanda Jackson. To the end of his life, Levi Jackson was devoted to Mary and proud of her every achievement. Mary stayed as busy over the next twenty years as she had been over the previous sixty-four, filling her days with her grandchildren and the volunteer work that gave her so much fulfillment. Mary Jackson died in 2005, and Gloria Champine penned a moving obituary that was published on the NASA website. "The peninsula recently lost a woman of courage, a most gracious heroine, Mary Winston Jackson," Gloria wrote. "She was a role model of the highest character, and through her quiet, behind-the-scenes efforts managed to help many minorities and women reach their highest potential through promotions and movement into supervisory positions."

Gloria, too, ended her thirty-year career at Langley in the equal opportunity office, building on Mary's legacy, making sure that no talent at Langley was overlooked. One of those whose careers she tracked was Christine Darden, the young mathematician who had been galvanized by Sputnik back in 1957. Christine's first years at Langley had been an exercise in enduring monotony. Though the Reentry Physics Branch had been an exciting place in the run-up to Apollo, long development lead times meant that by the time Christine came to the office, most of the interesting work had been completed, and the pace had slowed

significantly. Although Christine's pool was attached to an engineering group, most days she felt that she had entered a time machine. Many of the women in the pool of data analysts were former West Computers, and even though Christine had significant FORTRAN programming experience from her time in graduate school, a Friden calculator sat on her desk awaiting her input, just as it had for the computers in the 1940s. It was "deadly," she said. She was working for the organization that had just led the charge to the Moon, and yet in her corner of NASA, Christine felt like the future had passed her by.

It took persistence, luck, and more than a little cheek to break out of what had become such tedium that Christine thought many times about quitting. She had survived the Green Book RIF in 1970, but just prior to a second wave in 1972, she happened to overhear her boss talking to someone in the Human Resources Department: she was on the hit list! In the complex game of RIF chess, she was being knocked off the board by a black man who had been hired at the same time as her, but as a mathematician. He had been sent off to an engineering group and promoted; she, with less seniority, was slated for layoff.

The revelation spurred her to action. Rather than raise the issue with her boss, Christine went directly to the division chief—her boss's boss's boss, none other than John Becker, Langley's éminence grise, now on the cusp of retirement.

"Why is it that men get placed into engineering groups while women are sent to the computing pools?" Christine asked him. "Well, nobody's ever complained," he answered. "The women seem to be happy doing that, so that's just what they do." Becker was a man from another era. His wife, Rowena Becker, had been an "excellent mathematician"—the two met during the war, in the eight-foot tunnel—but after marrying she made the decision to leave Langley to become a full-time wife and mother. His frame of reference for working women and their expectations was like that of most men of his generation. But just as Becker had been willing to admit he was wrong when challenged by Mary Jackson in the 1950s, he rose to meet Christine Darden's challenge twenty years later. Two weeks after Christine walked into John Becker's office, she was assigned to a group working on sonic boom research.

Christine's new boss, David Fetterman, was a self-described "wing man" who had decided to stay in aeronautics even as others were moving to space. He was happy working on his research independently and assumed that his new charge felt the same way. So he handed Christine a fly-or-fail research assignment: she was to take the industry standard algorithm used to minimize sonic boom for a given airplane configuration (developed by Cornell researchers Richard Seabass and Albert George) and write a FORTRAN program based on it. It was work at aeronautics' leading edge, a computational fluid dynamics project that might help to mitigate the sonic boom that had made commercial supersonic flight so unpalatable.

It took three years of work, but the results were published in a 1975 paper entitled "Minimization of Sonic-Boom Parameters in Real and Isothermal Atmospheres." Christine was the sole author. The code she wrote as an aspiring engineer is still the core of sonic boom minimization programs that aerodynamicists use today. It was an important contribution and a career-making achievement, but the road from that breakthrough moment to becoming an internationally recognized sonic boom expert with sixty technical publications and presentations under her belt and a member of NASA's Senior Executive Service was still not direct.

In 1973, Christine took a computer programming course through Langley's partnership with George Washington University. She had excelled at Hampton Institute, powered through her master's degree at Virginia State, and finally landed a position with an engineering group at NASA, but the class of eight students—seven white and one black, seven men and one woman—was the first time she had been in an integrated school setting. She was intimidated at first, but high marks in the class made her decide to pursue a doctorate. Getting approval to enroll in the program took some doing. An upper-level supervisor denied her initial request. Even after she got the approval, she still was "juggling the duties of Girl Scout mom, Sunday school teacher, trips to music lessons, and homemaker," for her two daughters in addition to her full-time work at Langley.

The doctorate in mechanical engineering took ten years. It was bestowed upon her forty years after the first West Computers walked into Langley. Christine's success was supported by the work of the women who had come before her, her research based on the uncountable number of numbers that had passed through their hands and minds. Even with two of the finest credentials in the field to her name—a PhD and a major research contribution—it would take one more push before Langley acknowledged Christine Darden with the promotion that matched her accomplishments.

Gloria Champine admired Christine Darden's intelligence and the dogged way she had pursued her PhD. From her perch in the equal opportunity office, she knew that women at the center—even at the top levels—were still being leapfrogged by men, and Christine was one of them. By the mid-1980s, Christine had moved up to GS-13, but even with the doctorate, she was having problems breaking into GS-14. On the other hand, a white male engineer who had started at the same time, with similar quality performance reviews, had already hit the GS-15 level. Gloria knew the Langley way: "Present your case, build it, sell it so they believe it." She created a bar chart and showed it to the head of her directorate—a manager one level down from the top of Langley—who was shocked at the disparity. With Gloria's efforts, the promotion came, and after it, the renown and the mobility for Christine that should come to people with such outstanding abilities. It was one of Gloria's proudest moments. Christine had already done the work; Langley just needed someone who could help it see the hidden figures.

"What I changed, I could; what I couldn't, I endured," Dorothy Vaughan told historian Beverly Golemba in 1992. Dorothy retired in 1971 after twenty-eight years of service. The world had changed dramatically since the day she had taken the bus from Farmville to the war boomtown, but not quite enough to fulfill her last career ambitions. The Green Book landed on Dorothy's desk just two days after her sixtieth birthday. Her name was in the book, but it was not where she hoped it would be.

"It involved a promotion," Dorothy's daughter, Ann Vaughan Hammond, told me, though to exactly what, her mother never said. Dorothy played it close to the vest, giving her family only the barest sketch of her final disappointment. In all likelihood, she had expected to serve out her last few years as a section head, regaining the title she had held from 1951 through 1958. What a triumph it would have been to return to management, but as the head of a section that employed both men and women, black and white. The section head position was given to Roger Butler, a white man, who also held the post of branch chief. Sara Bullock, the East Computer who had been put in charge of the group programming the Bell computer back in 1947, was appointed head of one of the branch's four sections. Bullock was one of the rare female supervisors, particularly outside of administration. In 1971, there were still no female branch chiefs, no female division chiefs, no female directors at Langley.

And for the first time in almost three decades, no Dorothy Vaughan. Dorothy Vaughan's time as a supervisor back in the 1950s was relatively brief, but during those years she had midwifed many careers. Her name never appeared on a single research report, but she had contributed, directly or indirectly, to scores of them. Only reluctantly did she agree to a retirement party; she never liked it when people made a fuss. She discouraged her family from coming and found a ride (despite all her years in automobile-dependent Virginia, she never did learn to drive). Many of her new colleagues turned out to celebrate her, including her boss, Roger Butler. Of course, many of her old colleagues came too. Once upon a time they were girls who had come to Langley expecting a six-month war job; now they were older women with decades of membership in an elite scientific club. At one point in the evening, Lessie Hunter, Willianna Smith, and other West Computers gathered around their former supervisor for a picture, which was published the next week in the *Langley Researcher*. It was perhaps the only photographic evidence of the story that began in May 1943 with the Band of Sisters in the Warehouse Building. Though Langley was meticulous about documenting its employees over the years, individually and in groups, I have yet to stumble upon another Langley photo of the West Computing section.

Dorothy Vaughan had always loved to travel, and in retirement she

indulged herself, traveling for pleasure across the United States and to Europe. In her eighties she took a trip to Amsterdam with her family. At home, she remained as frugal as she had been during the Depression and the war, never spending when she could save, never discarding what she could salvage.

At some point, some years into her retirement, a woman came to the house, trying to enlist her in a class-action lawsuit over pay discrimination against the women who had worked at Langley. Dorothy sat on her couch and gave the woman a polite hearing, and then said: "They paid me what they said they were going to pay me," and that was the end of that. She never had been one to dwell on the past. After her retirement party, Dorothy Vaughan never went back to Langley. The photo album, the service awards, and the retirement gifts—all of them she tucked away in the keepsakes box in the back of the closet. The greatest part of her legacy—Christine Darden and the generation of younger women who were standing on the shoulders of the West Computers—was still in the office.